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Program Report

IT Enviroscience
Knoxville, TN

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16. ABSTRACT

EPA is developing new source performance standards under Section 111 of the Clean Air Act and national emission standards for hazardous air pollutants under Section 112 for volatile organic compound emissions (VOC) from organic chemical manufacturing facilities. In support of this effort, data were gathered on chemical processing routes, VOC emissions, control techniques, control costs, and environmental impacts resulting from control. These data have been analyzed and assimilated into the ten volumes comprising this report.

This volume contains a brief history of the four year project and includes emission ranking information for 140 manufactured organic chemicals.

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Organic Chemical Manufacturing
Volume 1: Program Report

Emissison Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

December 1980

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PROGRAM REPORT

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Office of Air Quality Planning and Standards
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March 1981

PREFACE

Concern over widespread violation of the national ambient air quality standard for ozone (formerly photochemical oxidants) and over the presence of a number of toxic and potentially toxic chemicals in the atmosphere led the Environmental Protection Agency to initiate standards development programs for the control of volatile organic compound (VOC) emissions. The Synthetic Organic Chemicals Manufacturing Industry (SOCMI) standards development program was initiated in 1976. Its purpose was to gather technical and cost data on the control of air pollution in organic chemical manufacture and then to prepare (1) New Source Performance Standards (NSPS) for total volatile organic compound (VOC) emissions, (2) Control Technique Guidelines (CTG) for VOC emissions, and (3) National Emission Standards for Hazardous Air Pollutants (NESHAP) for specific volatile organic chemical emissions. This program is part of the ongoing technical activities of the Emissions Standards and Engineering Division, Office of Air Quality Planning and Standards, EPA.

IT Enviroscience (ITE) contracted with the EPA to perform the task of gathering, assembling, and analyzing data and to evaluate the VOC emission control options available to SOCMI, assess their practicality, and develop preliminary design and cost-effectiveness conclusions for the most appropriate control options. Four years of work were needed to accomplish the program objectives. The efforts of many ITE and ESED engineers were required. The program organization chart is shown in Appendix A.

The project was initiated by David R. Patrick, who continued to lead the program as the EPA project officer for the first two and one-half years of the ITE contract. Jack R. Farmer served as project officer from September 1979 to January 1980, when the present EPA project officer, Robert E. Rosensteel, was given responsibility for the program. Ralph E. White served as full-time project manager for ITE.

During the first year of the ITE contract, ITE and ESED engineers worked together as teams for process site visits and data gathering. During this period Paul Clifford and Alan Goldfarb of Mitre Corporation contributed constructively as third-party advisors. Victor Kalcevic (ITE) and Leslie Evans (ESED) served as lead engineers throughout the program. Leslie Evans and David Beck (ESED) have made major contributions to data evaluation and report organization. The ITE task leaders are shown on the organization chart in Appendix A and are listed as report authors for the 54 reports comprising this 10-volume report, which is the final product of the complex four-year program.

CONTENTS

Page

I. INTRODUCTION I-1
  A. Background I-1
  B. Industry Description I-3
  C. VOC Emissions from the SOCMI I-4
  D. Technical Program I-5
  E. Summary I-7
II. HISTORY OF THE PROGRAM II-1
  A. Program Evolution II-1
  B. Survey and Ranking II-4
  C. Data Gathering II-5
  D. Confidentiality II-8
III. GENERIC REGULATIONS OF SOCMI EMISSIONS III-1
  A. Storage Vents III-1
  B. Fugitive Leaks III-1
  C. Waste Disposal III-2
  D. Process Vents III-2
IV. PROGRAM REPORTS IV-1
  A. Generic Process-Vent Standards IV-1
  B. Nonprocess Emissions IV-4
  C. Control Device Evaluations IV-5
  D. Product/Process Reports IV-5
V. TOTAL-VOC-EMISSION SUMMARY V-1
  A. Estimated Emissions V-1
  B. Conclusions V-3

APPENDICES

A. PROGRAM ORGANIZATION A-1
B. SURVEY AND RANKING B-1
C. ESTIMATES OF TOTAL SOCMI VOC EMISSIONS FOR 1982 C-1

TABLES

Number		Page
II-1	VOC Emission Estimates for 1982	II-6
IV-1	Emissions Associated with Unit Processes	IV-2
IV-2	Emissions Associated with Unit Operations	IV-3
IV-3	Cost-Effectiveness Summary of Control Devices	IV-6
IV-4	SOCMI VOC Emissions Addressed	IV-7

FIGURES

Number		Page
II-1	Number of Products Ranked	II-2

I. INTRODUCTION

The Synthetic Organic Chemicals Manufacturing Industry (SOCMI) program was initiated to gather the data necessary to develop New Source Performance Standards (NSPS) and Control Techniques Guidelines (CTG) for volatile organic compound emissions from organic chemical manufacturing. The data would also support development of National Emission Standards for Hazardous Air Pollutants (NESHAP) for benzene and other organic hazardous pollutants to be listed in the future.

The total SOCMI program is complex because the industry is large and complex. First, there are at least 400 or 500 major, commercially significant, organic chemicals being manufactured by 600 to 700 processes. Second, the industry is technologically advanced, growing, and highly competitive; thus new chemicals and processes are being constantly introduced. Finally, a significant portion of the emissions from this industry are from fugitive leaks, storage and handling losses, and secondary sources rather than from process vents.

For these same reasons it was also decided to pursue a new approach to regulation. Consequently, the program was designed to result in generic standards for manufacture of organic chemicals. In other words, instead of writing standards for each of 600 to 700 different processes, the EPA intends to write a relatively limited number of standards for the unit operations (physical processes) and unit processes (chemical processes) in use in the SOCMI. Thus standards would regulate the emissions without regard to the chemical. Aside from providing the best hope of quickly and efficiently regulating a highly complex and constantly changing industry, this approach also provides the added benefit of controlling toxic chemicals now and potentially toxic organic chemicals before they are specifically found to be toxic.

A. BACKGROUND

The SOCMI program was initiated in March 1976 with the formation of an EPA Hydrocarbon Task Force. Their charge was to conceive of and initiate a program that would lead to regulation of air emissions from the organic chemicals industry. It was generally understood that a process and equipment standard approach would be needed, although plans for implementation had not been formulated. Obviously, the first goal was to develop a well-structured, logical program within reasonable resource and time requirements.

Several activities preceded initiation of the program. Energy and Environmental Analysis, Inc., and GCA/Technology Division were asked to outline work plans for generating the information required to implement an air-pollution control program for manufacture of organic chemicals. Concurrently, Monsanto Research Corporation was asked to identify critical organic chemical processes and operations with respect to their pollution potential. Their reports are on file at EPAs Emission Standards and Engineering Division. The results of these studies and internal CMS planning then led to a request of the Mitre Corporation to develop a Request for Proposals (RFP) for a program, to be competitively bid (Mitre is not eligible to bid competitively against profit-making concerns), for gathering the information necessary to develop regulations for organic chemical manufacture. After extensive collaboration, Mitre provided a draft RFP. This draft was further refined by EPA and then submitted to EPA Contracts for bid and award.

During the period preceding award of the ITE contract several other projects were undertaken. First, Mitre was asked to identify and rank potential organic air toxicants. This resulted in the 5-volume report Preliminary Scoring of Selected Organic Air Pollutants, EPA 450/3-77-008. In that report 643 organics were identified that are produced in quantities of about 1 MM (million) lb/yr or more. Pertinent physical, chemical, toxicological, and production data were summarized and the chemicals rank-ordered on the basis of emission potential toxicity.

ORD/IERL, Cincinnati, also completed at that time a study by Radian entitled Organic Chemical Producers Data Base, which was useful in establishing the flow of basic organic chemicals and in initially pinpointing important chemicals, manufacturers, and locations. Other ORD and ESED work available or in progress at that time was also useful.

As a supplement to locating the preliminary chemical industry data, Mitre was asked to identify and survey all pertinent organic chemical information sources, to evaluate those sources, and to provide an annotated bibliography on organic emissions from the SOCMI. This resulted in Mitre report MTR-7377.

A decision document and a public participation plan were prepared. Final program approval by the EPA Administrator was received on September 29, 1976 (copy in CMS files). Following a Federal Register notice on October 22, 1976, announcing the program, additional notification was given to approximately 100 major chemical companies, state and local agencies, public interest groups, and interested federal agencies.

The program planning phase officially ended with the contract award to IT Enviroscience in March 1977.

B. INDUSTRY DESCRIPTION

Organic chemicals are manufactured in an industrial chain that begins with about ten feedstock materials produced principally in petroleum refineries. These feedstocks then proceed through one or more processing tiers that result in literally thousands of final products. Generally speaking, each tier contains more chemicals than the preceding tier, the plants manufacturing the products are smaller than the plants supplying the feedstock, and the volatilities of the product are lower than those of the feedstocks. For these reasons in its early stages the SOCMI program was narrowed to the basic and intermediate organic chemical manufacturing industry, which encompasses about 350 to 400 of the higher volume, higher volatility products. These chemicals are also predominately manufactured in large-scale, continuous processes.

For various reasons about 65% of the SOCMI volume is produced in Texas and Louisiana, although other plants are located in most industrialized areas of the country. Each plant site may manufacture from one to several organic chemicals, using one or more processes. Most processes result in one basic product, although some produce a family of chemicals. Conversely, many chemicals are produced by more than one process. Yearly production quantities at each plant can range from a few million to several billion pounds.

Each SOCMI chemical is generally manufactured by a small number of companies (this averages less than 10, with a range of 1 to more than 20). The SOCMI chemicals are also generally manufactured at a small number of separate plant sites (this, too, averages less than 10, but ranges from 1 to more than 50). Many companies operate more than one plant to manufacture the same chemical.

When these variations are combined with differences in plant age, location, and operation, it is not surprising that few chemical plants are alike. This is true even within a single company manufacturing the same chemical at different sites. An added complication is that many chemical companies license processes from other chemical companies or third parties, often foreign.

Finally, the SOCMI is a highly competitive industry whose economic lifeblood is technology and that is characterized by rapid growth and technological change. Thus the introduction of new and more economical processes is common, as is the termination of older processes that are no longer economical. Under these conditions it is understandable that the industry is highly protective of its technology.

The above description of the SOCMI clearly shows why regulation of VOC emissions from this industry in the normal way, i.e., by individual chemical process, would have been very difficult. That approach would have necessitated literally hundreds of individual standards. Furthermore, each standard would affect only a limited number of plants and would have to be changed frequently as the industry changed. This would be neither cost effective nor practically achievable. Obviously, a more generalized approach to regulating VOC emissions from the SOCMI was necessary.

C. VOC EMISSIONS FROM THE SOCMI

Preliminary analysis showed that, although the SOCMI is complex and diverse, VOC emissions occur from four main types of sources: vents on storage and transportation vessels (storage and handling emissions), leaks and spills of VOC (fugitive emissions), evaporation of VOC from solid, liquid, and aqueous wastes (secondary emissions), and process vents. Each source is briefly described below.

Emissions from storage vents occur predominately as working and breathing losses from fixed- and floating-roof tanks, and those from transportation vessels result from filling and breathing. Fugitive emissions are principally leaks from defective or inadequate seals in such equipment as pumps, valves, and compressors. They also include losses from open-ended valves, sampling purge material, and cooling towers. Secondary emissions, so-called because they frequently occur away from the process site at a wastewater treatment plant or landfill, result from waste disposal and include evaporation of VOC from solid, liquid, and aqueous wastes generated within the process. Emissions of VOC from process vents occur predominately as the result of venting of inert gases or from the release of volatiles that cannot be economically captured. Upset releases also fall in this category.

Total SOCMI VOC emissions are projected to be about 1.4 billion lb/yr by 1982. This estimate is adjusted on the basis of a 5.9% industry growth rate per year. Of this amount 9% are attributed to storage losses, 32% to fugitive emissions, 4% to secondary emissions, and 55% to process vent emissions. These estimates are based on Texas and Louisiana emission inventory data supplemented with detailed information obtained through a large number of plant visits and industry inquiries. Uncontrolled plant emissions range from a few thousand to many millions of pounds per year. The total VOC emission estimate is less than half of that presented in the earlier report, Control Techniques for Volatile Organic Emissions from Stationary Sources, EPA-450/2-78-022 (May 1978) and likely reflects recent pollution control efforts by the industry and inaccuracies in the earlier estimates.

D. TECHNICAL PROGRAM

Development of a broad approach to regulate VOC emissions from the SOCMI was initiated in 1976 based on the suggestions of B. J. Steigerwald, EPA. The initial goal was to develop an expeditious method for preparation of NSPS, for the organic chemical industry, that would broadly control both oxidant precursors and potentially toxic organics. A number of possible approaches were identified and assessed. Some of the important problems that were recognized were (1) how to factor toxicity and reactivity into regulations, (2) the lack of authority at that time for EPA promulgating equipment standards, and (3) the uncertainty of methodology for economic analysis.

After three short studies were initiated with contractors to assess some of the problems. GCA/Technology Division and EEA, Inc., recommended longer range EPA activities aimed at efficient regulation of the SOCMI. Monsanto Research Company evaluated the possible use of unit operations and unit processes in SOCMI regulation. After these studies were completed and reviewed, an RFP was issued in July 1976, and a contract was awarded to Hydroscience, Inc. (a wholly owned subsidiary of the Dow Chemical Company) in March 1977. In April 1980 the Knoxville, Tennessee, operations of Hydroscience, Inc., underwent a name and ownership change. The Hydroscience Tennessee operation became IT Enviroscience (ITE), a wholly owned subsidiary of IT Corporation, a California-based environmental management company whose major interests are in hazardous waste treatment, recycle, and disposal. The contract performance continued uninterruptedly under the new entity.

Although structured to generate data and report on unit processes and unit operations, the SOCMI contract laid out only the broad concept of the regulations. ITE was required only to develop relevant technical and cost data, in a form to be agreed upon with the EPA; then the EPA would prepare standards. Actual standards preparation was not planned as part of this contract because the successful bidder was required to have detailed chemical industry experience. Standards development by such a contractor would likely involve conflicts of interest.

After award of the contract EPA and ITE developed a detailed work plan that was believed to be capable of providing the necessary documentation for the desired generic standards. That work plan identified storage and handling, fugitive leaks, and waste disposal as separate emission sources and as sources that could more quickly lead to a generic regulatory package than could the unit processes/unit operations. The work plan also called for the preparation of detailed technical reports on the manufacture of the 350 or 400 SOCMI chemicals. These reports would be prepared by a small number of very detailed early studies being conducted first and then the level of details progressively reduced and extrapolated to a larger number of later studies. Each chemical report would thus require less effort than the one preceding it.

The first work plan was predicated on several assumptions: (1) It was believed that the SOCMI was easily separable into 350 or 400 chemicals and that there were significant emissions from most of these. (2) It was assumed that data existed in public and/or open industry files on a majority of the emission sources. (3) It was assumed that there were sufficient similarities between the many chemical manufacturing processes to allow extrapolation across chemical and process lines. (4) It was assumed that some well-controlled examples existed for a majority of emission sources as the result of state or local regulation. These assumptions had to be changed as discussed in the next section.

At the beginning of this program the problem of developing the proper data base for standards and guidelines to cover the manufacture of literally thousands of organic chemicals in hundreds of different processes seemed almost insurmountable. However, after careful analysis of the industry and its sources and an extensive review of basic chemical engineering literature, a solution began to emerge. First, it was found that the bulk of emissions come from the manufacture of a limited number of chemicals. Next, it was found that, although the manufacture of organic chemicals is complex and diverse, VOC emissions occur in only four ways: (1) emissions from storage tanks and transportation vessels, (2) fugitive leaks and spills, (3) losses of VOC from liquid, aqueous, and solid wastes, and (4) emissions from process vents. The solution to the standards problem, then, was to develop a data-base program suitable for standards and guidelines specific to the four sources. These were designated generic because they represented a limited number of standards capable of encompassing a large number of different emission sources independent of the specific chemical and process.

E. SUMMARY

This 10-volume report is the final product of the ITE contract for assessment of SOCMI VOC emissions and evaluation of emission control options. This program report constitutes Volume I. Following is a brief description of the contents of the remaining volumes of this final report:

1. Volume II: Analysis of Emissions from Carrier Gas Producing Reactions, Air Oxidation Process Emissions, Vacuum System Emissions, and Upset Releases

This volume contains a detailed discussion of the carrier-gas generic standard approach and explains its use for projecting VOC emissions. Through four separate reports the generic approach is used to demonstrate the projection of VOC emissions from chemical reactions in general, air-oxidation processes specifically, vacuum operations, and potential emissions from upset releases. The VOC emissions discussed in these four reports cover essentially all VOC process emissions from SOCMI. Each report also discusses the control options applicable for the VOC emissions projected.

2. Volume III: Analysis of Fugitive Emission Sources, Storage and Handling, and Secondary Emission Sources

This volume contains three reports covering the VOC emission estimates from nonprocess sources. The available control options are discussed, and a cost analysis is presented for each appropriate control device. The EPA plans to develop generic NSPS for the control of VOC emissions covered by Volumes II and III.

3. Volume IV: Control Device Evaluations of Thermal Oxidation, Catalytic Oxidation, and Flares

Volume V: Control Device Evaluations of Carbon Adsorption, Absorption, and Condensation

The combustion control devices covered by Volume IV plus the three control device reports of Volume V cover all of the significant add-on VOC emission control devices used by SOCMI. The reports include descriptions of the control devices, their capabilities and limitations in controlling VOC emissions, control efficiencies, cost of control, and environmental impact considerations. This work is intended to be the most comprehensive and up-to-date assessment of VOC emission controls developed by the Office of Air Quality Planning and Standards (OAQPS). These volumes should be valuable not only for selecting and evaluating control options for emission sources within SOCMI but also for other VOC emission sources.

4. Volumes VI—X: Chemical Process Reports

The last five volumes of the report are a consolidation of 39 ITE product reports. Each product report is an in-depth technical analysis presenting information on the plants producing a particular chemical product or products, typical production routes, associated VOC emissions, feasible emission controls, control costs (from a new-plant perspective), and other impacts from application of the controls. These studies substantially constitute the data base for the generic source analyses of Volumes II and III.

All of the data presented in the 39 product reports of Volumes VI-X and the non-process emission reports of Volume III are given in the metric system. This is in keeping with the EPA overall plan to convert to the metric system. By the time these reports were completed, it became apparent that the effort required for this conversion was much more time consuming and costly than had been anticipated. Industry had also expressed strong opposition to the conversion. Furthermore, the concepts covered by the control device evaluations and generic process emission studies are quite complex and comprehension of these concepts would be considerably more difficult if presented in the metric system. Therefore, all of the data in the remaining reports were retained in conventional English units.

5. Product Report Grouping

The chemicals covered in each product report volume are listed in each table of contents. Basically the chemicals are grouped according to the type of feedstock used in their production. The chemicals in Volume VI and VII are produced from cyclic chemical feedstock (mainly benzene and cyclohexane). The chemicals in Volume IX are produced from C_1 and C_2 feedstocks, and those in Volume X are produced from C_3 and C_4 feedstocks. Volume VIII was formed from the decision to include all the major halogenated chemical products in one volume.

II. HISTORY OF THE PROGRAM

A. PROGRAM EVOLUTION

As the study progressed through its first two years the original perception of the SOCMI study underwent drastic changes as the result of data that were gathered from over 75 plant visits, several hundred detailed inquiries of SOCMI companies, and detailed surveys of the Texas and Louisiana air pollution files. Some of the conclusions that were reached, particularly as they relate to the assumptions existing at the time that the program was initiated, are as follows:

First, perhaps as many as two-thirds of the 350 or 400 chemical processes appear to result in negligible nationwide emissions, with the exception of storage and fugitive emissions, with the bulk of industry emissions appearing to be concentrated in the highest volume processes. Figure II-1 shows the cumulative percent of SOCMI estimated emissions for the top 140 ranked products. (The top 140 ranked products are shown in Appendix B.) The 140 ranked products result in almost 90% of the total estimated SOCMI emissions. It can be concluded from this that detailed work on 140 chemicals would be much more cost effective than work on 350 or 400 chemicals.

Second, it became apparent that information on emissions was scarce, particularly for smaller sources Even the manufacturers themselves do not have data in many emission areas. Furthermore, the emission inventory information in state files was often estimated, as well as frequently confidential and therefore not easily accessible. Also, technical literature was general and was rarely directed toward air emissions. These facts further argued against preparation of 350 or 400 documents and argued for the broader generic approach.

Next, although unit operations and unit processes appeared to be sufficiently similar across chemical processes to allow generic process emission standards to be developed at completion of the program, each complete chemical process was so different that extrapolation across processes for efficiency in report preparation appeared to be virtually impossible. This raised further questions concerning the feasibility of preparing 350 to 400 specific chemical reports.

Number of Products Versus Percent of Total 1982 Emissions Addressed

18

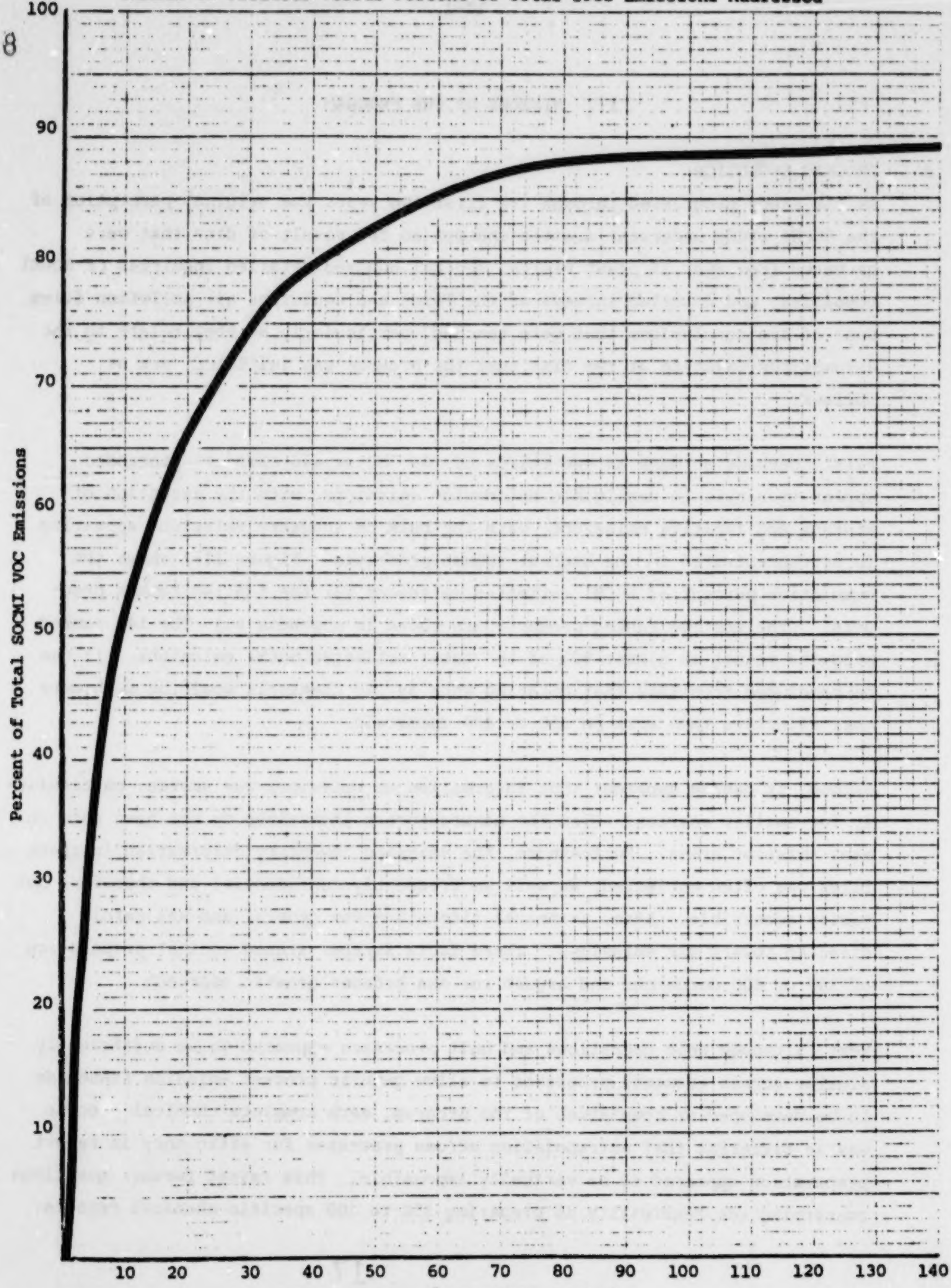

Fig. II-1 Number of Products Ranked

Finally, although there are many well-controlled plants, many are still significant emitters. State regulations have been responsible for some control, but only a few states have vigorously pursued regulation of the SOCMI. A factor very important to emission reduction has been the controls applied for other than air pollution reasons, for example, odor, flammability, and high chemical costs.

As a result of these findings the program plan was revised to focus on fewer individual chemicals and processes. The revised approach required focus by ITE on the top 140 chemicals and preparation of detailed technical reports for only the more significant ones. Storage, fugitive, and secondary emissions remained as major subject categories, and unit process/unit operation data continued to be gathered for generic process emission standards. Analysis continued to indicate that the ability to develop the necessary industry-wide regulations would not be adversely affected. In other words, the data necessary to support the desired generic standards still appeared to be available, even though fewer individual processes were to be studied.

The only major program casualty was the loss of a large number of individual chemical process CTGs. It had been originally planned that up to 350 or 400 chemical process CTGs would be written as described above. This number had to be dramatically reduced. However, this loss does not appear to be serious, for the following reasons. CTGs are most effective when they apply to a large number of separate sources in several states, when the sources are in nonattainment areas, and when little control is currently present. Since the majority of the emission sources are located in Texas and Louisiana, a large number of CTGs could prove burdensome to those state agencies. Furthermore, many sources are in attainment areas, which would reduce the effectiveness of the CTGs. Finally, many sources are already controlled, and so the CTG benefit would be further reduced. All these facts indicate that the incremental benefits of a large number of CTGs would be marginal at best.

The more reasonable approach appeared to be to prepare individual chemical process CTGs on only the larger, more widely dispersed, and less well-controlled processes and to supplement them with the planned CTGs for storage, fugitive, waste disposal, and unit processes/unit operations, along with technical reports on other chemicals for information. Not only would this approach be most likely to best interface with the NSPS program, but it would also probably help state and local agencies to best utilize their resources in meeting their needs to attain the oxidant standard as expeditiously as possible and to control problem chemical processes.

B. SURVEY AND RANKING

At the program inception it was apparent that an important factor in the success of the overall program was going to be the ranking of processes in order of importance. It was considered necessary for the generic concept that unit operations and unit processes be evaluated in proportion to their importance. If the generic concept turned out not to work, it would be important to have studied the most important emission sources for regulation. It was also considered important that the processes with the more toxic emissions take some measure of precedence over those with less toxic emissions. Therefore an extensive survey and ranking operation was established. The goal of this operation was to compile all pertinent data related to VOC emissions, growth, process design, and toxicity. Preliminary survey and ranking studies had previously been performed by Radian and Mitre, but those studies had incorporated simplifying assumptions that were not adequate for the depth and degree of effort expended by this program. By using the Radian and Mitre studies as starting points and incorporating Monsanto Research Corporation studies, Houdry studies, and data from the Texas and Louisiana Air Control Agencies (covering 65% of SOCMI), the resulting survey and ranking tables of Appendix B were believed to be the most up-to-date, complete, and accurate VOC emission projections from SOCMI available. However, several changes have occurred during the programs that necessitated major adjustments.

Prior to this program previous studies had indicated that, in general, storage and handling emissions constituted approximately 8% of SOCMI VOC emissions, fugitive emissions ~20%, and secondary emissions up to 5%. As the result of more recent studies the estimate for storage and handling emissions is now 9%, fugitive emissions 32%, and secondary emissions up to 4%. These estimates are discussed in detail in their respective reports in Volume III. The initial estimates were with reference to a total 1982 SOCMI VOC emission projection of approximately 1779 MM lb. The current estimate is based on a revised total

1982 VOC emission projection of 1434 MM lb. As a result of the detailed studies covered by the 39 product reports presented in Volumes VI—X, there is every indication that the VOC emissions from the SOCMI have been dramatically reduced.

Table II-1 is a comparison of the initial emission estimates and current estimates for nearly all the individual processes studied and reported in Volumes VI—X. Since the initial estimates were made, the fugitive-emission factors have essentially doubled, the storage-emission factors have decreased, and the secondary emission estimate has remained unchanged. The updated factors have been applied to all components of the current estimate. As with any such table, inconsistencies persist. With both estimates care was taken to include all emissions but avoid double counting. During preparation of the initial program estimates it was often necessary to prorate combined emission data from several different processes. In some cases this proration was very inaccurate and may distort the comparison of emissions for specific products, but does not diminish the accuracy for larger groups of products.

The results clearly indicate that the VOC emissions from the processes studied are only half the emissions estimated at program initiation. Since both emission estimates were created from data reported by industry, it appears that the SOCMI has accomplished a dramatic reduction of VOC emissions. Indications are that, if studies are continued for all products listed in Appendix B, a similar reduction of VOC process emissions would be observed.

C. DATA GATHERING

At the program inception it was reasoned that the air quality control agencies for many states would be visited, requiring a large number of trips to be made to several states. It was soon determined that approximately 65% of SOCMI was concentrated in Louisiana and Texas, especially the first- and second-tier chemicals of major interest for this program. Therefore early efforts were concentrated on obtaining industry emission data from the Louisiana and Texas Air Control Agencies. Both agencies extended excellent cooperation, and after careful attention to prevent the release of confidential information approximately 7000 pages of emissions data were copied that contributed greatly to the survey and ranking information included in this report.

Table II-1. VOC Emission Estimates for 1982

Product	Production (MM lb)	Growth (%)	VOC Emissions (MM lb) Current Estimate	VOC Emissions (MM lb) Initial Estimate
Acrylonitrile	2,440	8	145.50	254.00
DMT/TPA	8,243	8	99.38	141.41
Ethylene dichloride	14,005	5	90.92	116.48
Ethylene	33,138	4.5	73.31	81.97
Propylene oxide	2,420	5	29.54[a]	49.98
Formaldehyde	7,539	4.5	27.42	40.91
Cyclohexanol/cyclohexanone	2,448	1.5	26.52	43.35
Acetic acid	3,315	5	23.4[a]	26.80
Acrylic acid	788	8	22.48	25.38
Ethylene oxide	6,105	5	21.39	137.87
Maleic anhydride	451	8	16.46	36.18
Butadiene	3,956	3	15.83[a]	12.50
Ethylbenzene/styrene	6,831	6	15.75	57.84
Ethylene glycols	5,447	4	15.59	15.24
Fluorocarbons	1,009	5.5	11.44[a]	5.00
Phenol/acetone	3,287	4.5	9.68	32.23
Methanol	9,423	7	8.31	38.49
Cyclohexane	2,779	5	4.40	1.80
Chloromethane/MeOH	1,929	8	4.17	2.85
Perchloroethylene	834	0	3.9[a]	4.40
Acetic anhydride	1,555	1	3.18[a]	18.45
Alkylbenzene	607	2	3.17	0.08
Caprolactam	1,071	5.5	2.86[a]	4.88
Toluene diisocyanate	684	3.5	2.81[a]	6.52
Chlorobenzene	405	0	2.70	2.25
Chloromethane/methane	440	0	2.37	11.19
Nitrobenzene	752	7	1.67	3.70
Vinyl acetate	2,055	6	1.37[a]	19.73
Carbon tetrachloride	519	(-10.0)	1.21	9.54
Cumene	3,282	4.4	0.98	3.99
Epichlorohydrin	378	5.5	0.68[a]	1.88

Table II-1. (Continued)

	Production	Growth	VOC Emissions (MM lb)	
Product	(MM lbs)	(%)	Current Estimate	Initial Estimate
Glycerin	125	0	0.59[a]	21.48
1,1,1-Trichloroethane	710	6	0.48	14.89
Chloroprene	396	3	0.41[a]	13.69
Acrolein	50	2	0.24[a]	6.13
Adipic acid	2,020	4.5	0.18	0.41
Aniline	833	8	0.16[a]	2.66
Glycol ethers	833	5	0.14[a]	0.47
Methyl ethyl ketone	653	5	0.11[a]	0.43
Ethyl acetate	183	3	0.04[a]	1.21
Acetaldehyde	988	3.5	0.01[a]	7.27
	136,013		726	1373.78
Waste sulfuric acid recovery[b]			7.26	
			733	

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[a] Estimates were doubled because the study estimate for these products did not include storage, fugitive, or secondary emissions.

[b] Was not a part of the initial emissions estimate.

Technical data collection from industry was initiated through the Chemical Manufacturers Association (CMA) and the Texas Chemical Council. Three meetings were held during the first year, including a detailed presentation of the data ITE had assembled on the first ten processes. CMA technical work groups were set up to assist with data collection and to review the ITE draft reports. Draft report reviews by industry and the CMA task groups have been very helpful in improving the quality and accuracy of reports throughout the program.

To obtain the industry data required, it was necessary to have direct contact with the production managers for the products involved. This necessitated more than 60 process discussions involving more than 30 separate companies. On some occasions brief plant tours were included, and on other occasions central meetings were held with a group of production managers during which several processes were covered. In all cases the ITE engineers studied previous EPA reports concerning the process and available technical literature. The ITE engineers always prepared moderately detailed process flow sheets before making the site visit so that discussions of process emissions and factors related to VOC emissions would be as efficient and rewarding as possible. The process information prepared before site visits also established the data as being in the public domain and therefore nonconfidential.

D. CONFIDENTIALITY

After the program was initiated, an additional problem surfaced that necessitated some program redirection. Although it had been anticipated that some resistance would be encountered when data were being gathered that might be considered as proprietary, the determined resistance from some industries was found to be greater than the EPA had expected. It became apparent that the SOCMI, perhaps more than any other industry studied by the ESED, considers their process technology, know-how, and other information to be absolutely vital to their competitive positions. Therefore both ESED and ITE had to spend an inordinate amount of time (weeks) on problems dealing with trade secrets, confidentiality agreements (in excess of 50 agreements between ITE and over 30 separate companies), and in general working out mechanisms by which industry would release information needed for the program and still retain their proprietary protection.

The standard procedure employed by ITE to protect industry's confidential data was to allow the company to thoroughly review all notes. In many instances all plant visit notes were left with the companies. Any data considered confidential was so indicated or removed. Trip reports were always submitted to the company before release to ensure that they contained no confidential data. No company data were ever reproduced in a product report that did not already appear in the released nonconfidential trip report. At the conclusion of this program confidential data will not be retained by ITE but will be forwarded to ESED, returned to the company, or destroyed.

Although some of the confidential data obtained during the program were useful for verifying design concepts and emission factors, the quality of the reports has not suffered by their exclusion. The most common problem was the desire of industry to keep specific plant capacities and production rates confidential; however, industry always agreed to reveal the emission factors (lb of VOC emission/lb of product), which were the most important data required for this program. To project total emissions from a chemical process, ITE used the model-plant approach as explained in the product reports (Volumes VI—X), combined with production and capacity data from published literature.

When industry was given the opportunity to review draft product reports, they realized that none of their confidential information was revealed and the fear of releasing proprietary information to the public was abated. Once the problem of confidentiality was cleared, industry was quick to realize that it was in their best interest to aid in the development of reports that were as practical and accurate as possible, with an absence of large data gaps that would have required further effort. The cooperation by industry in general has been excellent.

III. GENERIC REGULATIONS OF SOCMI EMISSIONS

As was discussed earlier, are only four major sources of emissions: storage vents, fugitive leaks, waste disposal, and process vents. Although the methods of control differ for these four sources, in each case the emissions result from the volatility of the organic chemicals involved, the conditions (e.g., temperature, pressure, and inert-gas flow) that affect volatility, and the potential for emission (e.g., vent release, high inert-gas flow, etc.). Thus it was assumed from the beginning of the program that all these sources could be regulated and that regulations could be independent of specific chemical or process; that is, that they could be generic in nature. A second assumption was that generic regulation of SOCMI could result in the same degree and extent of control that would be obtained by the more normal process specific regulations but with far fewer total regulations. Finally, analysis indicated that storage, fugitive, and secondary controls should be relatively straightforward but that process vent control would be much more complicated.

A. STORAGE VENTS

Storage emissions are easily characterized and identified. In fact, equations were generally available at program inception both for predicting emissions and pinpointing factors affecting them. The major difficulty in the SOCMI program was characterization of storage in the chemical industry, since this effort spans hundred of chemicals, thousands of tanks and vessels, and a wide range of volatility. Computer assistance was applied to adequately deal with these variables. The regulatory approach, nevertheless, was straightforward. Control equipment (pressure tanks, floating-roof tanks, and add-on control devices)will be required, depending on the volatility of the stored material, the size of the tank or vessel, and analysis of the impacts of the control.

B. FUGITIVE LEAKS

Fugitive emissions were also expected to be easily characterized and identified. Potential leak sources were well known, with predominant emissions coming from defective valve, pump, and compressor seals. The regulatory approach was again seen as straightforward, centering on better housekeeping through a directed leak detection and maintenance program. Certain equipment requirements were also envisioned, all of which were to be based on the potential for leakage, which includes consideration of the physical state of the leaking material and the frequency of seal failure. The major difficulties would be in defining the leak potential in the SOCMI and in establishing the best approach for leak detection. Because of the occupational exposure that results from most fugitive leaks, coordination with the Occupational Safety and Health Administration (OSHA) was also expected to be necessary.

C. WASTE DISPOSAL

Secondary emissions were expected to be significant but difficult to define since little relevant literature appeared to be available. The SOCMI program was thus designed specifically to gather information relating to solid, liquid, and aqueous waste streams and the VOC content of those streams. Control of emissions at the waste disposal or treatment sites was beyond the scope of this program; however, focus on control of VOC entry into the waste streams was believed to hold great promise as a general and environmentally sound method of emission reduction. Thus standards were planned to improve plant operation and maintenance. The major difficulty expected to be encountered was lack of data, and thus quantification, on the part of industry. Coordination with pending regulations under the Resource Recovery and Conversation Act (RRCA) was expected to be necessary.

D. PROCESS VENTS

Process vents in the SOCMI create several unique problems that make regulation of air emissions difficult. Normally a regulation is developed to cover a source that is common to a sizable industry segment. In this case, however, there are literally thousands of different process vents associated with the many processes involved in the manufacture of SOCMI chemicals. Waste gases also span a wide range of chemical and physical properties. For these and other reasons, process vents required a more general approach to regulation than had been used in the past.

Chemical engineering principles suggested a way to handle this problem. First, all chemical manufacturing is made up of unit processes and unit operations. Chemical reactions, such as oxidation and chlorination, take place in unit processes. Physical changes, such as separation and drying, take place in unit operations. Although a large number of different unit processes and unit operations are known, only a small number are both widely used in the SOCMI and capable of emitting significant quantities of VOC.

Next, although there is a wide range of emissions from process vents, only a few different reasons exist for their release. These reasons include pressure relief, removal of inert gases or other undesired volatiles, and evacuation of equipment for vacuum processing. Analysis further indicated that the major causes of SOCMI emissions are release of inert gases or reaction gases and venting of VOCs when their capture is not economical.

The approach to regulation of process vents, then, was to focus on only the significant unit processes and unit operations and to develop regulations around common gas-stream properties.

Several problems were anticipated: (1) Many separate chemical processes would have to be examined in order for sufficient data to be obtained to support standards. (2) It would have to be determined whether the unit processes and unit operations were similar enough across different manufacturing processes to permit common regulations, which, in fact, might not be determined until late in the data-gathering effort. (3) A method of performing the impact analyses for process vent standards, as with the other generic standards, would have to be developed. Nevertheless, it was believed that these hurdles could be overcome. Add-on controls would likely form the basis for process vent control, although improved operation and maintenance should also find use. Size and volatility cutoffs would probably be necessary, depending on the results of the impact analyses.

IV. PROGRAM REPORTS

This final report contains all the specific study reports developed throughout the program. It is intended to serve as the formal compilation of technical and cost data to support the standards to be developed covering process-vent emissions, storage emissions, fugitive emissions, secondary sources, and any other standards developed as a result of this program.

A. GENERIC PROCESS-VENT STANDARDS

The generic process-vent-emission reports comprise Volume II. The approach to development of generic process-vent standards is conceptually straightforward. First, a theoretical prediction of maximum VOC concentration in the emission was developed and the major influencing variables were identified. These variables were checked against the data gathered for the 39 product reports contained in Volumes VI—X. A similar procedure was developed to project flow rate ranges, primarily based on an inert-gas flow relationship. These concepts are explained in detail in Volume II.

A range or regime of potential waste-gas concentrations and flows was established. With reference to the control device evaluations of Volumes IV—V, the control device options applicable to each flow regime are discussed. The next step planned in the subsequent program to develop standards for these process-vent emissions will be to determine cost effectiveness based on the costs presented in the control device evaluation reports and to determine the cost impacts on industry. These economic analysis steps are not part of the SOCMI program covered by this report. However, specific cost-effectiveness determinations are presented for the products reported on in Volumes VI—X.

Preliminary estimates indicated the relative emission contributions of the various unit processes and unit operations shown in Tables IV-1 and IV-2. Through analyses of this type of data, including the distribution of reaction modules, process modules, and control modules (Survey and Ranking, Appendix B), it was determined that the process-vent emissions could be essentially covered by the process-emission reports presented in Volume II. The principal emission mechanism and the most important variable is inert-carrier-gas flow. Attempts to characterize this variable have been reasonably successful, with stoichiome-

Table IV-1. Emissions Associated with Unit Processes

Unit Process	No. of Products Produced Using Unit Process	No. of Ranked Products Containing Unit Process	Estimated Contribution to Total Unit Process Emissions (%)	Cumulative Contribution (%)
Oxidation	63	43	48.3	48.3
Halogenation	67	43	14.5	62.3
Hydrogenation	26	13	10.8	73.1
Esterification	24	8	6.9	80.0
Alkylation	15	5	4.0	84.0
Sulfonation	11	6	3.4	87.4
Dehydrogenation	15	4	2.7	90.1
Hydrolysis	27	8	2.4	92.5
Reforming	1	1	2.2	94.7
Carbonylation	10	8	1.2	95.9
Oxyacetylation	1	2	1.0	96.9
Nitration	12	1	0.8	97.7
Dehydration	18	4	0.7	98.4
Ammonolysis	11	6	0.6	99.0
Condensation	51	4	0.5	99.5
Dealkylation	4	1	0	99.5*

*Less than 100 because of rounding errors.

Table IV-2. Emissions Associated with Unit Operations

Unit Operation	No. of Times Unit Operation Used in the SOCMI	Estimated Contribution to Total Unit Process Emissions (%)	Cumulative Contribution (%)
Absorption	475	58.1	58.1
Scrubbing/washing	543	27.9	86.0
Distillation	3651	10.4	96.4
Drying	251	3.3	99.7
Filtration	120	0.1	99.8
Extraction	110	0	99.8
Settling	24	0	99.8
Crystallization	144	0	99.8*
Separation	384		
Quenching	146		
Evaporation	127		
Ion exchange	120		
Dilution	71		
Mixing/blending	56		

*Less than 100 because of rounding errors.

try, vapor pressure, and explosive limits being the major factors influencing waste-gas VOC concentrations. The methodology of projecting waste-gas flow and VOC concentrations is described in detail in Volume II.

The conclusion from the above estimates was that a limited number of process-vent standards may very well successfully result in a high degree of coverage of the SOCMI process vents. To be significant and not economically prohibitive, VOC emissions must have either low concentration/high volume or high concentration/low volume. Furthermore, highly efficient, widely applicable control mechanisms for these two types of exit gas streams are limited in number. Therefore present analysis indicates that only very few generic standards will be necessary to deal adequately with SOCMI process vents. The principal difficulty will be in developing appropriate techniques for economic analysis.

B. NONPROCESS EMISSIONS

Volume III presents the nonprocess-emission studies for storage, fugitive, and secondary sources. Based on test results reported by the EPA the estimate of emissions from storage-tank vents has been reduced. This is because the AP-42 emission equations used to estimate storage losses have been found to overstate the breathing losses by a factor of 4.

Fugitive emissions consist primarily of leaks from equipment handling the flow of VOC, i.e., pumps, flanges, and valves. The fugitive emissions estimates reported by this study are based on equipment count estimates for the processes studied and fugitive emission factors provided by other EPA contract studies. These fugitive emission factors are much greater than the emissions factors used at the start of the program and the estimates for fugitive emissions have been increased accordingly.

Even though a serious attempt was made during site visits to obtain data for estimating emissions resulting from VOC waste disposal, very little useful information was obtained. Industry apparently had done very little to assess this situation. Based on the information obtained and with heavy reliance on theoretical calculations, the secondary VOC emissions are estimated to be approximately 90 MM lb/yr. The EPA plans to conduct a sampling program to improve this estimate and to establish a better basis for regulation.

C. CONTROL DEVICE EVALUATIONS

Volumes IV and V discuss in detail the VOC emission control devices used throughout the SOCMI. For comparison purposes Table IV-3 lists the resulting relative cost-effectiveness estimates for the ranges of VOC concentrations and flow rates for each applicable control device. Table IV-3 does not include the very-high-temperature thermal oxidation required for VOC containing halogens or sulfur, nor does it include flares since they are primarily dedicated to intermittent flows at very high flow rates.

D. PRODUCT/PROCESS REPORTS

Table IV-4 lists all the individual products and processes studied during the program. These studies are covered by the 39 reports that constitute Volumes VI—X of this final report. The primary consideration for selecting the product to be studied was the amount of VOC emissions estimated for 1982. Toxicity was also an important selection factor, as is discussed in Appendix B. For study and site visit efficiency, products and processes were studied in groups. Therefore some products were covered that appear far down the survey and ranking list of Appendix B. Even though the studies were initiated on a priority basis, the final completion dates are out of sequence. The product studies shown in Table IV-4 are listed in the essentially random order of completion.

As shown by Table IV-4, the 39 product reports have addressed 64 products manufactured by 97 processes. These reports account for approximately 80% of the SOCMI VOC emissions initially projected for 1982. Since approximately 30% of the SOCMI VOC initial emission estimate is covered by the reports for fugitive, storage and handling, and secondary emissions, this total program has addressed approximately 85% of the total SOCMI VOC emissions. Not counted are the VOC emissions addressed by the generic process-emission reports.

Table IV-3. Cost-Effectiveness Summary of Control Devices[a]

VOC Concentration (ppm$_v$)	Flow Rate (scfm)	Cost Effectiveness (per lb of VOC Removed)				
		Thermal Oxidation[b]	Catalytic Oxidation[b]	Carbon Adsorption[c]	Gas Absorption[c]	Condensation[c]
1,000	100					
	1,000	$2.30	$1.80	$0.63	$1.28	
	5,000	0.90	0.73	0.27	0.83	
	50,000	0.60	0.41	0.12	0.55	
	100,000	0.56	0.39	0.11		
5,000	100					0.62
	1,000	0.43	0.32	0.15	0.33	0.14
	5,000	0.17	0.12	0.08	0.14	
	50,000	0.10	0.05	0.05	0.11	
	100,000	0.10	0.05	0.05		
10,000	100					0.32
	1,000	0.19	0.17		0.17	0.08
	5,000	0.06	0.05		0.07	
	50,000	0.03	0.02		0.05	
	100,000	0.03	0.02			
25,000	110					0.14
	1,000	0.08			0.07	0.03
	5,000	0.03			0.04	
	50,000	0.02			0.02	
	100,000	0.02			0.02	

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[a] Values in some cases interpolated from cost effectiveness given in individual control device reports.

[b] Based on recuperative heat recovery.

ed on no credit for VOC.

Table IV-4. SOCMI VOC Emissions Addressed

Product	Process	1982 Emissions (%)[a]
Maleic anhydride	Benzene oxidation	2.2
	Butane oxidation	
Cyclohexane	Benzene	0.1
	Petroleum extraction	
Ethylbenzene	Benzene alkylation	2.9
Styrene	Benzene alkylation	0.4
Methylene chloride	Methanol	0.1
Chloroform	Methanol	0.0
Methyl chloride	Methanol	0.1
Nitrobenzene	Benzene nitration	0.2
Ethylene	E/P cracking	4.6
	N/G cracking	
Propylene	E/P cracking	1.9
	N/G cracking	
Acrylic acid	Propylene oxidation	1.4
	HP modified Reppe	
Methyl acrylate	Direct esterification	
Ethyl acrylate	LP modified Reppe	0.2
Butyl acrylate	Direct esterification	0.0
2-Ethylhexyl acrylate	Trans-esterification	
Chlorobenzene	Benzene chlorination	0.1
o-Dichlorobenzene	Benzene chlorination	
p-Dichlorobenzene	Benzene chlorination	
Acrylonitrile	Propylene ammoxidation	14.3
Hydrogen cyanide	Propylene ammoxidation	2.5
Cyclohexanol/ cyclohexanone	Cyclohexanone oxidation	2.4
	Phenol hydrogenation	
Linear alkylbenzene	Paraffin chlorination	0.0
	Paraffin dehydrogenation	
Adipic acid	Nitric acid oxidation	0.0

Table IV-4. (Continued)

Product	Process	1982 Emissions (%)[a]
Formaldehyde	Dehydrogenation/oxidation - silver catalyst	2.3
	Oxidation - metal oxide catalyst	
Ethylene dichloride	Direct chlorination	6.5
	Oxychlorination	
Ethylene oxide	Air-oxidation	7.7
	Oxygen-oxidation	
Butadiene	*n*-Butane dehydrogenation	0.7
	n-Butene oxidative dehydrogenation	
	Ethylene by-product	
Vinyl acetate	Ethylene vapor phase	1.1
Methyl chloride	Methane chlorination	0.0
Methylene chloride	Methane chlorination	0.3
Chloroform	Methane chlorination	0.3
Carbon tetrachloride	Methane chlorination	0.0
Acetaldehyde	Ethylene air-oxidation	0.4
	Ethylene oxygen-oxidation	
Acetic anhydride	Acetic acid pyrolysis	1.0
Glycol ethers	Ethylene oxide	0.0
Fluorocarbons	Fluorination	0.2
Methyl methacrylate	Acetone cyanohydrin	2.9
Acetic acid	Methanol carbonylation	0.3
Acetic acid	Butane oxidation	0.6
Acetic acid	Acetaldehyde oxidation	0.6
Formic acid	Butane oxidation	0.0
Methyl ethyl ketone	Butanol dehydrogenation	0.0
Ethyl acetate	Esterification	0.1
Carbon tetrachloride	Hydrocarbon chlorinolysis	0.3
Perchloroethylene	Hydrocarbon chlorinolysis	
Epichlorohydrin	Allyl chloride	0.1
Allyl chloride	Propylene chlorination	0.7
Acrolein	Propylene oxidation	0.3

Table IV-4. (Continued)

Product	Process	1982 Emissions (%)[a]
Allyl alcohol	Allyl chloride hydrolysis	0.0
	Propylene oxide	
Glycerin	Epichlorohydrin	0.5
Glycerin	Acrolein	0.0
	Allyl alcohol	
Methanol	Methane	2.2
Caprolactam	Conventional	0.2
Caprolactam	BASF	0.1
Caprolactam	DSM/HOP (Stamicarbon)	0.0
Toluene diisocyanate	Diaminotoluene	0.4
Ethanolamines	Ethylene oxide	0.1
Dimethyl terephthalate	Via TPA	1.0
Dimethyl terephthalate	Hercofina	5.6
Terephthalic acid	Oxidation and purification	1.8
1,1,1-Trichloroethane	Vinyl chloride	0.8
	Ethane chlorination	
Perchloroethylene	EDC chlorination	0.2
	EDC oxychlorination	
Trichloroethylene	EDC chlorination	
	EDC oxychlorination	
Vinylidene chloride	Trichloroethane	0.1
Cumene	Phosphoric catalyst	0.2
	Alumium chloride catalyst	
Ethylene glycol	Ethylene oxide	0.9
Sulfuric acid	Direct evaporation	0.2[b]
	Indirect evaporation	
	Regeneration	
Propylene oxide	Chlorohydrination	2.6
Propylene oxide	Isobutane hydroperoxidation	0.1
	Ethylbenzene hydroperoxidation	0.1
Chloroprene	Butadiene	0.8
Aniline	Nitrobenzene hydrogenation	0.1
Phenol	Cumene	1.1
Acetone	Cumene	0.5
		79.4

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[a] Percent of initial 1982 SOCMI emission projections addressed.

[b] Emissions from waste sulfuric acid recovery not initially considered.

V. TOTAL-VOC-EMISSION SUMMARY

A. ESTIMATED EMISSIONS

The generic reports of Volume III present independent estimates of the total SOCMI VOC emissions. These estimates are based primarily on study data of 1978 and have not been projected to 1982.

	VOC Emissions (MM lb)
Storage and handling	80
Secondary	90
Fugitive	460-700

The estimate of total SOCMI emissions presented in the Storage and Handling report in Volume III is 35% lower than the estimate for 1982 projected from the product study reports. This is because the average vapor pressures estimated in the Storage and Handling report are lower than those observed during the product studies and the fact that the Storage and Handling report is based on 1978 data.

For the estimate of total SOCMI emissions presented in the Secondary Emissions report in Volume III it is assumed that the VOC in wastewater has the average vapor pressure of the products. The actual average vapor pressure may be somewhat lower and therefore result in fewer secondary emissions. The secondary emissions projected from product studies are based on a very limited amount of actual data. Both estimates are only order-of-magnitude estimates and the difference between the two estimates presented for secondary emissions is considered to be within the accuracy expected.

The above emissions estimate for fugitive emissions is based on data collected in 1978. The fact that new plants come on stream every year indicates that fugitive emissions would be expected to increase. However, this is largely offset by the fact that many older obsolete plants are shut down and replaced with modern high volume facilities with reduced fugitive emissions because fewer valves and pumps are used for handling a greater volume of VOC liquids.

The above range of 460 to 700 MM lb of VOC fugitive emissions per year represents the difference between an estimate that the SOCMI has the same degree of fugitive emissions control as observed by a petroleum industry study (defined by this program as uncontrolled emissions) and an estimate that the SOCMI averages 50% of the maintenance and monitoring prescribed to control fugitive emissions. Based on the observations made during the performance of this program and the SOCMI incentives concerning economics, odor, toxicity, and regulatory pressures, it is estimated that the SOCMI fugitive VOC emissions in 1982 will be approximately 460 MM lb.

Based on the SOCMI product studies in Volume VI-X, the emission estimates in Tables II-1 and C-1, and the futitive emissions estimate explained above, the total VOC emissions projected for 1982 are estimated to be 1434 MM lb. The initial projection for 1982 was 1779 MM lb. The methods for determining these projections are explained in Appendix C. The breakdown of this 1982 emission projection by source is as follows:

	VOC Emissions (MM lb)	Amount (%)
Process	792	55
Fugitive	460	32
Storage and handling	124	9
Secondary	58	4
	1434	100

As shown in Table IV-1 and discussed in the Air Oxidation Emission Projection report in Volume II, oxidation process reactions contribute close to 50% of all process-source emissions. From the standpoint of unit operations the greatest volume of VOC emissions is contributed by vacuum systems. As is discussed in the Vacuum System Emission Projections report of Volume II, the number of vacuum systems incorporated by the SOCMI is difficult to estimate, but these systems are believed to contribute at least 158 MM lb of VOC per year.

While the studies described in Volumes VI—X were being conducted, particular attention was given to the potential for benzene emissions. Following is a summary of the SOCMI benzene emissions projected for 1982. Over 90% of the benzene emissions result from the manufacture of four products.

Product	Estimated Benzene Emissions (MM lb/yr)
Maleic anhydride	12.78
Ethylbenzene/styrene	6.83
Ethylene	2.81
Alkylbenzene	2.62
Nitrobenzene	1.17
Chlorobenzene	0.92
Caprolactam	0.04
Acetic anhydride	0.02
Aniline	0.01
Total	27.20

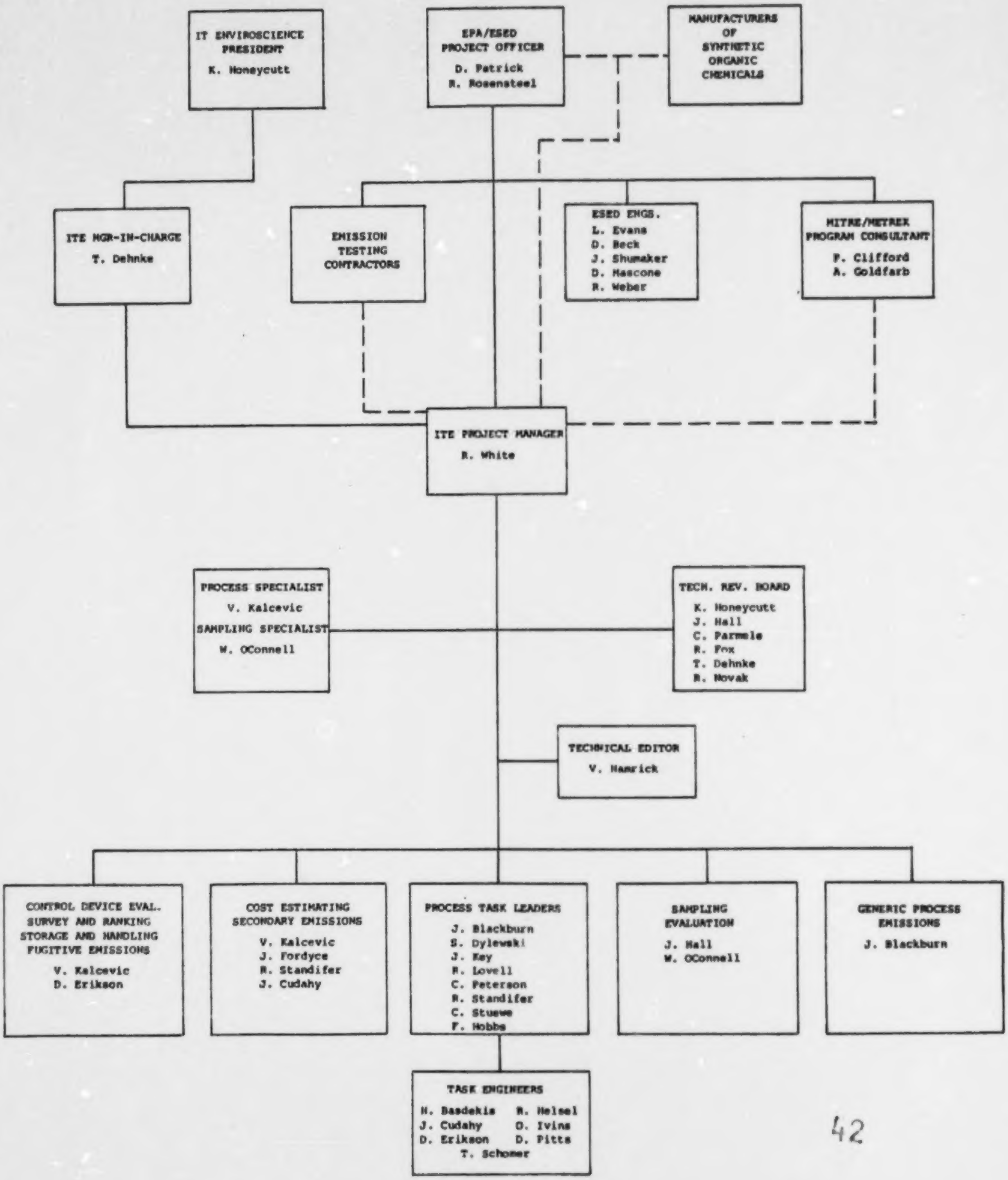
B. CONCLUSIONS

As shown in Table II-1 and discussed in Appendix C, the estimated emissions from the manufacture of the products studied are only about half the initial estimate made early in the program. The initial estimate was based largely on Louisiana and Texas Air Control Agency data supplied to them by industry surveys for 1975 and 1976. The current estimate is based on site visits to many of these same industry sources. The evidence clearly shows that a dramatic improvement in emissions from the SOCMI has occurred during the last few years. The greatest improvement has been in the control of emissions from process vents. The motivation for these improvements obviously includes the economic advantage of VOC loss prevention, industry's genuine concern for the environment, plus current and anticipated regulatory pressures.

APPENDIX A

PROGRAM ORGANIZATION

APPENDIX A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PROGRAM ORGANIZATION

APPENDIX B

SURVEY AND RANKING

APPENDIX B

SURVEY AND RANKING

The primary objective of the survey and ranking task was to provide the necessary data to rank order the processes to assure that the most significant processes were studied in the most detail early in the project.

This report describes the methods used and gives the results for ranking 140 products.

Four areas were identified and considered to rank order the processes:

1. Gross Emissions - The total quantity of non-methane hydrocarbons emitted from the manufacture of a specific compound by each one or more processes annually.
2. Growth Factor - The projected rate of annual growth expected through 1982. Very low or negative growth compounds were given lower priority than potentially high growth compounds.
3. Modular Contribution - A breakdown of the various manufacturing processes into the specific types of reaction processes and emission control modules associated with each process. Primary emphasis was given to processes which would yield information that could be utilized to help study similar aspects of other processes.
4. Toxicity Score - A means of differentiating the potential health hazards between processes that emit varying amounts of less toxic and more toxic chemicals.

Gross Emissions Determination

Total annual production multiplied by an emission factor (lbs. material lost per lb. of product) yields the annual gross non-methane hydrocarbons (NMHC) emissions. 1976 was used as the base year since it was the most recent year for which complete actual production data could be obtained. Production data was supplied by the annual chemicals manufacturing report in Chemical and Engineering News and Chemicals Economics Handbook published by Stanford Research Institute.

Information used to determine emission factors was gathered from the Texas and Louisiana State Air Control Boards. Non-confidential emissions inventories, some selected construction permit files in Louisiana, and most of the pertinent non-confidential construction permit files in Texas were also used when available.

Considerable judgment was used in calculating emission factors from the data in the inventory questionnaires and permits. Many files did not contain adequate production breakdowns for individual plant sites. In these cases, plant production was estimated by taking the capacities listed in The Chemical Marketing Reporter Chemical Profiles or the 1976 Directory of Chemical Producers and multiplying by the average industry percentage of production in relation to capacity. Several questionnaires did not contain sufficient information to enable the designation of which emission point originated with which process. When apparently good analytical data was available and the vented emissions were broken down into components, the processes could be separated with some degree of certainty.

In some cases, where multiple processes used common vents, the emissions had to be allocated, usually on a weight percentage basis of production. Judgments were also required even when all information was available and emission factors could be readily calculated. The factors for two similar facilities were often quite dissimilar. If a factor for one facility agreed well with published data, then that factor was selected as being more accurate. In some cases, where no comparable data was available, an average was taken. In a number of cases, the calculated emission factors were rejected as being unreasonably below expected levels.

In those cases where an emission factor could not be obtained because of the reasons stated above or because there were no producing sites in Texas and/or Louisiana, the Radian, Monsanto, or Houdry data were used when available.

When a compound was produced by two or more distinctly different processes, emission factors were determined for each significant method of manufacture. Radian's production percentage breakdown for each process was used where revised data were not available. The VOC emissions estimated for the top 140 chemicals are shown by Table I.

Growth Factor Determination

Rank ordering is based on 1982 projected gross NMHC emissions. Since most pre-1975 growth projections are invalid due to the economic recession of 1975, revised figures were needed. The source of these revised projections were the Chemical Economics Handbook and Chemical Marketing Reporter. Using the new growth rates, the 1982 gross emission data was obtained by compounding the 1976 data over six years. The average annual growth was approximately 6%.

Modular Contribution

The various units which comprise the anatomy of a synthetic organic chemical production plant had to be broken down and identified. Although each plant has an individual character of its own, there are still common operations or sections which can be related to other processes. These sections or modules were assigned to three categories: reaction, process, and emission control. Reaction modules describe the initial portion of the process where the compound is made, i.e., alkylation, oxidation, chlorination, etc. Process modules comprise the various unit operations that the compound or product must go through during its manufacture and which can result in the release of emissions, i.e., distillation, absorbtion, extraction, etc. Emission control modules define the device or devices used to prevent or control emissions, i.e., flare, condensor, thermal oxidizer, etc.

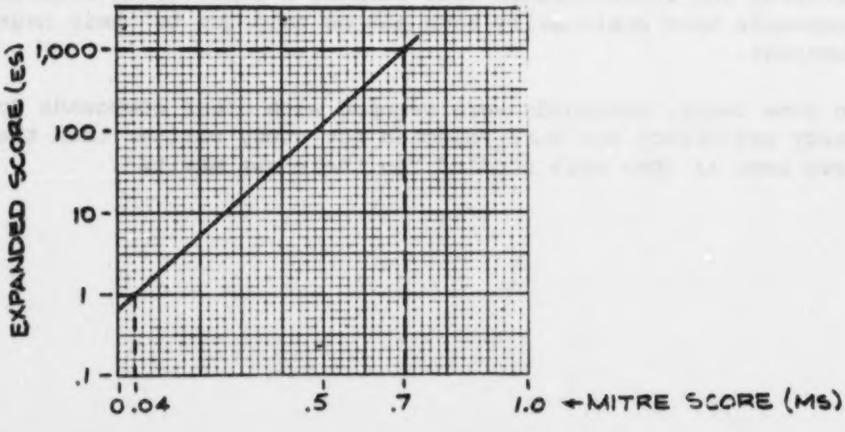
Modular contribution was a judgment assessment of the value of studying a particular process with regard to the transfer of emission related technology to other process studies where similar process modules can be identified. Three (3) grids depicting the various reaction, process, and emission control modules are shown in Tables II, III, and IV.

Toxicity Score Determination

Toxicity score was obtained by multiplying the annual gross emissions (broken down by MM lbs. of each major component) by a toxicity factor assigned to each component. These quantities are then totaled, resulting in a toxicity score for the compound under consideration. (See Figure 1 as an example).

Two methods were used to determine the toxicity factor and resulting toxicity score.

Exponential toxicity scores were computed from the EPA's formula which uses the MITRE toxicity ratios. The MITRE scoring (EPA-450/3-77-008a) has been "expanded" to show more accurately the "real" difference in toxicity between less toxic and more toxic chemicals. In the MITRE system a very toxic chemical, vinyl chloride, has a score of 0.7 while a typical chemical, with few toxic properties, methylal, has a score of 0.04. The ratio between these two MITRE scores is only 17.5. A judgment was made that the ratio of 1000 better shows the real difference in toxicity of these two chemicals, then the MITRE scoring was used as an exponent to calculate an "expanded score". The formula for the expansion is $ES = .657\,e^{10.5\,(MS)}$



The expanded score was used in the same way as the MITRE score would be used. The toxicity score is obtained by multiplying the expanded score by the MM lbs. of VOC emissions. The exponential toxicity scores are shown in Table I.

Linear toxicity scores were computed by multiplying the component gross emissions (MM lbs.) times two different toxicity numbers. The first number, ranging from 1 to a maximum of 6, represents the MITRE score plus 1 for acute toxicity. This is consistent with other toxicity scoring such as the one sited in "Clinical Toxicity of Commercial Products". The second number represents the carcinogenic, mutagenic, and teratogenic potential. If a compound was given a 4 or 5 per the MITRE score in any or all of the three categories, it was assigned a 5; if under test, a 3, and if it had not been tested or had scored a negative result, it was given a 1. (See Figure 1 for example). The maximum toxicity factor for this method was 6 x 5 = 30. The minimum was 1 x 1 = 1. The linear toxicity scores are also shown in Table I.

Rank Ordering

The processes, as rank ordered for this study, are listed in Table I. All four of the areas previously described were considered in rank ordering the compounds for selection. The 1982 total projected NMHC emissions were given the most weight in a selection decision; however, modular contribution and toxicity scores were used to choose between compounds having relatively equal amounts of gross emissions.

The study ranking table is ranked according to the most significant process for each compound. The secondary processes are grouped under each compound, and the decision regarding their study priority is made on an individual process comparison basis. Process studies were grouped for practical study convenience.

Other factors also entered into the selection process. Vinyl chloride, for instance, was omitted for study, even though it ranked first because a considerable amount of effort and resulting reports have already been compiled on this compound. Processes which use benzene as a raw material such as nitrobenzene, chlorobenzene, and linear alkyl benzene were assigned early in the project as a result of increased governmental interest and investigation into benzene's toxological effects. Some compounds have arbitrarily been put on hold due to their negative growth forecast.

In some cases, compounds were grouped with other compounds for practical study efficiency and were selected for study earlier than they would have been if they were studied "on their own merits".

This method of survey and ranking is considered to be a significant improvement over previous methods because of the following incorporations:

1. Actual plant data, regarding the quantity and composition of emissions, was used to calculate emission factors in the majority of cases.

2. Toxicity scores are based on the relative toxicity and amount of each individual component in the emission, not just the compound or product being manufactured.

3. The chemical manufactures in the states of Texas and Louisiana, which were used as the data source, accounting for approximately 65% of the total U.S. synthetic organic chemical production.

FORMALDEHYDE

FIGURE 1

Production M Pounds	x	Emission Factor lb/lb of Product	Component	=	Annual Gross Emissions M Pounds	x	EPA Exponential Toxicity Factor	=	Toxicity Score
5621.0	x	.00077	Formaldehyde	=	4.330	x	152.10	=	659.0
		.00036	Methanol	=	2.020		4.59	=	9.3
		.00400	Ethanol	=	22.480		2.75	=	61.8
		.00513			28.830				730.1

Linear Toxicity Score

Component	Gross Emissions	x	Acute Toxicity Factor	x	Teratogen Carcinogen Mutagen	=	Toxicity Score
Formaldehyde	4.330	x	4	x	5	=	86.6
Methanol	2.020	x	4	x	1	=	8.1
Ethanol	22.480	x	3	x	1	=	67.4
	28.830						162.1

Growth Rate = 6%/Year (Over next 6 years, i.e. 1982)

Gross Emissions	28.83 x 1.419 = 40.92	1982 Projected - See (→) on Tables II, III, and IV
Exponential Toxicity	730.1 x 1.419 = 1036	
Linear Toxicity	162.1 x 1.419 = 230	

TABLE I

SURVEY AND RANKINGS PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	RANK	1982 TOXICITY SCORE EXPON.	RANK LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
1	VINYL CHLORIDE		1%	ACETYLENE	.395	6.99%	.593	105	27	110	.00689	B
			99%	ETHYLENE DICHLORIDE	40.034	6.99%	60.080	5	1	6	.00704	B
2	ACRYLONITRILE	KEY	100%	PROPYLENE OXIDATION	151.496	8.99%	254.0*	1	5	3	.09979	A/B
3	ETHYLENE DICHLORIDE	KEY	0%	ACETYLENE								
		KEY	50%	DIRECT CHLORINATION	29.494	7.36%	45.165	10	4	1	.00759	A
		KEY	50%	OXYCHLORINATION	46.569	7.36%	71.314	4	3	2	.01199	B
4	MALEIC ANHYDRIDE	LAWSON	85%	BENZENE OXIDATION	23.165	9.15%	39.180	13	2	4	.09334	A/B
		LAWSON	15%	BUTANE OXIDATION								
5	ETHYLENE OXIDE	LOVELL	66%	AIR OXIDATION/ ETHYLENE	91.955	5.99%	130.4*	2	9	7	.03329	C
		LOVELL	34%	O2 OXIDATION/ ETHYLENE	5.263	5.99%	7.466	40	96	84	.00369	C
6	DIMETHYL TEREPHTHALATE (DMT)	DYLEWSKI	23%	AMOCO VIA TPA	5.551	7.99%	8.809	34	80	55	.00861	C
		DYLEWSKI	35%	DUPONT	2.204	7.99%	3.499	64	66	33	.00224	C
		DYLEWSKI	17%	EASTMAN VIA TPA	3.084	7.99%	4.894	54	90	68	.00647	C
		DYLEWSKI	25%	HERCULES	63.209	7.99%	100.3*	3	28	5	.09029	C
7	ETHYLENE	STANDIFER	46%	NAPTHA GAS OIL PYROLYSIS	22.355	14.47%	50.302	8	11	19	.00342	D
		STANDIFER	52%	NATURAL GAS LIQUIDS PYROLYAS	29.619	1.11%	31.664	15	16	23	.00190	D
		STANDIFER	2%	REFINERY BY PRODUCT								
8	ETHYLBENZENE	KEY	98%	BENZENE ALKYLATION	32.250	7.93%	51.000	6	6	8	.00600	A
		KEY	2%	MIXED XYLENE EXTRACT	.072	-13.1*	.031	158	170	169	.00017	
9	HYDROGEN CYANIDE (HCN)	BLACKBURN	50%	ACRYLONITRILE COPRODUCT	29.999	6.49%	43.773	11	17	17	.09979	A/B
		BLACKBURN	50%	ANDRUSSON PROCESS	2.464	6.49%	3.596	63	33	31	.00819	A
10	STYRENE	KEY	100%	ETHYL BENZENE	4.535	6.99%	6.807	43	7	22	.00071	C
11	I.I.I. TRICHLOROETHANE	STANDIFER	10%	ETHANE CHLORINATION								
		STANDIFER	74%	VINYL CHLORIDE	8.876	8.99%	14.886	23	8	9	.01899	B
		STANDIFER	16%	VINYLIDENE CHLORIDE								
12	CARBON TETRACHLORIDE	STUEWE	38%	CARBON DISULFIDE	5.209	-4.00%	4.077	59	10	29	.01599	B

TABLE I

SURVEY AND RANKING PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	1982 GROSS NMHC EMISSIONS RANK	1982 TOXICITY SCORE RANK EXPON.	1982 TOXICITY SCORE RANK LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
12	CARBON TETRACHLORIDE	STUEWE	42%	CHLOROPARAFFIN CHLOROLYSIS	6.117	-4.00%	4.788	56	43	51	.01699	B
13	FORMALDEHYDE	STUEWE	20%	METHANE	.956	-4.00%	.670	101	39	80	.00499	A
		LOVELL	23%	METAL OXIDE/ METHANOL	6.632	5.99%	9.407	32	48	32	.00512	A
		LOVELL	77%	SILVER CATALYST/ METHANOL	22.203	5.99%	31.496	16	26	10	.00512	A
14	METHYL METHACRYLATE (MMA)	BLACKBURN	100%	ACETONE CYANOHYDRIN	32.972	7.49%	50.886	7	58	14	.06049	A/B
15	PROPYLENE OXIDE	STUEWE	60%	CHLOROHYDRIN	35.067	5.80%	49.199	9	46	12	.02959	B
		STUEWE	40%	PEROXIDATION	.433	10.45%	.786	100	125	104	.00070	A
16	PROPYLENE		54%	NAPTHA/GAS OIL PYROLYSIS	12.730	14.49%	28.673	17	19	26	.00342	D
			16%	NATURAL GAS LIQUIDS PYROL	3.049	7.49%	4.706	58	49	76	.00189	D
			30%	REFINERY BY PRODUCT								
17	NITROBENZENE	STUEWE	100%	BENZENE NITRATION	2.268	8.49%	3.701	61	12	27	.00299	D
18	ETHYLENE GLYCOL	LOVELL	100%	ETHYLENE OXIDE	10.742	5.99%	15.238	22	13	21	.00319	A
19	CYCLOHEXANOL/ CYCLOHEX-ANONE	BLACKBURN	75%	CYCLOHEXANE	35.020	3.49%	43.048	12	63	15	.04446	A
		BLACKBURN	25%	PHENOL	.241	3.49%	.296	123	127	128	.00091	A
20	CUMENE	STUEWE	100%	BENZENE	2.661	6.99%	3.994	60	14	37	.00097	A
21	METHANOL (METHYL ALCOHOL)	KEY	100%	METHANE	25.550	6.99%	38.494	14	62	19	.00410	A
22	PHENOL	STUEWE	3%	BENZENE CHLORINATION								
		STUEWE	2%	BENZENE SULFONATION								
		STUEWE	93%	CUMENE	12.627	6.99%	18.950	19	21	13	.00621	A
		STUEWE	2%	TOLUENE OXIDATION								
23	ANILINC	STUEWE	100%	NITROBENZENE HYDROGENATION	1.631	8.49%	2.661	67	15	35	.00299	D
24	FLUOROCARBONS	STANDIFER	100%	CCI4/C2CI6 FLUORINATION	5.001	.00%	5.001	52	18	43	.00499	B
25	PERCHLOROETHYLENE	STANDIFER/*	0%	ACETYLENE								
		STANDIFER/*	66%	ETHYLENE DICHLORIDE	1.253	15.59%	2.991	66	34	44	.00544	B
		STANDIFER/*	34%	METHANE	1.314	1.22%	1.413	89	23	64	.00499	A
26	TEREPHTHALIC ACID (TPA)	DYLEWS<I	39%	AMOCO	4.334	7.99%	6.878	42	83	63	.00854	C
		DYLEWSKI	47%	EASTMAN	6.201	7.99%	9.841	30	64	28	.01014	C
		DYLEWSKI	14%	MOBIL	10.033	7.99%	15.922	21	81	34	.05512	C

TABLE I

SURVEY AND RANKINS PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS VMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	1982 GROSS NMHC RANK	1982 TOXICITY SCORE EXPON.	RANK LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
27	CHLOROBENZENE	DYLEWSKI	100%	BENZENE CHLORONATION	1.996	1.99%	2.248	74	20	53	.00434	B
28	ACRYLIC ACID	BLACKBURN	23%	MODIFIED REPP	.218	-4.12%	.169	132	149	134	.00195	A
		BLACKBURN	77%	PROPYLENE OXIDATION	10.933	14.93%	25.205	18	32	20	.08703	B
29	ACETIC ACID	KEY	33%	ACETALDEHYDE	10.012	1.82%	11.158	27	56	16	.00980	B
		KEY	44%	BUTANE OXIDATION	.342	77.43%	10.692	28	71	39	.00704	B
		KEY	19%	METHANOL	2.915	9.07%	4.911	53	77	69	.00749	B
		KEY	4%	OTHERS								
30	CHLOROPRENE	DYLEWSKI	100%	VIA BUTADIENE	11.875	2.39%	13.691	24	29	11	.03149	A
31	ALKYL LEADS		5%	ELETROLYSIS								
			95%	ETHYL CHLORIDE	4.827	-11.0*	2.399	71	22	71	.00812	A
32	ACETONE	STUEWE	69%	CUMENE	5.658	7.05%	8.517	35	30	24	.00521	A
		STUEWE	31%	ISOPROPANOL	5.102	-1.13%	4.765	57	87	52	.00649	B
33	ETHYL CHLORIDE		4%	ETHANOL/ETHANE								
			96%	ETHYLENE CHLORINATION	8.672	-7.00%	5.611	49	25	30	.01349	B
34	ETHANOLAMINES	LOVELL	100%	ETHYLENE OXIDE	1.431	2.99%	1.709	84	24	45	.00499	B
35	VINYL ACETATE (VA)	DYLEWSKI	13%	ACETYLENE VAPOR PHASE	1.630	6.99%	2.447	70	92	73	.00846	C
		DYLEWSKI	72%	ETHYLENE VAPOR PHASE	6.515	6.99%	9.777	31	65	25	.00610	C
		DYLEWSKI	15%	ETHYLENE LIQUID PHASE	5.002	6.99%	7.507	39	61	38	.02251	C
36	METHYLENE CHLORIDE	STUEWE	35%	METHANE CHLORINATION	3.561	9.01%	5.978	47	38	42	.01699	B
		STUEWE	65%	METHANOL/METHYL CHLORIDE	.638	12.18%	1.273	90	51	58	.00194	A
37	1.3 BUTADIENE	STANDIFER	80%	ETHYLENE COPRODUCT	4.011	14.04%	8.827	33	36	61	.00267	D
		STANDIFER	13%	N-BUTANE	7.157	-12.2*	3.270	65	108	83	.00610	B
		STANDIFER	7%	N-BUTENE	.978	-11.1*	.481	108	150	140	.00166	B
38	VINYLIDENE CHLORIDE	STANDIFER	50%	1,1,1 TRICHLOROETH.	1.772	6.99%	2.660	68	31	48	.01899	B
		STANDIFER	50%	1,1,2 TRICHLOROETH.								
39	TOLUENE DIISOCYANATE (TDI)	STANDIFER	100%	DIAMINOTOLUENE	3.984	8.99%	6.515	45	35	40	.00699	A/B
40	CHLOROFORM	STUEWE	61%	METHANE CHLORONATION	5.017	8.99%	5.060	51	41	49	.01699	B
		STUEWE	39%	METHANOL CHLORONATION	.221	8.99%	.371	119	73	86	.00194	A
41	PHTHALATE ANHYDRIDE		30%	NAPTHALENE								
			70%	O-XYLENE	1.338	6.49%	1.953	76	37	47	.00211	A

TABLE I

SURVEY AND RANKINS PROCESS STUDIES

SEL. NK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	1982 GROSS NMHC EMISSIONS RANK	1982 TOXICITY SCORE RANK EXPON.	1982 TOXICITY SCORE RANK LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
42	ISOPROPANOL (ISOPROPYL ALCOHOL)		100%	PROPYLENE/H2SO4	4.566	1.99%	5.142	50	40	60	.00235	A
43	ACETIC ANHYDRIDE	KEY	100%	ACETIC ACID	15.452	2.99%	18.451	20	74	62	.01009	B
44	GLYCEROL (SYNTHETIC ONLY)	PETERSON	14%	ACOLEIN	.421	1.99%	.474	109	122	130	.01909	C
		PETERSON	15%	ALLYL ALCOHOL	.756	1.99%	.852	98	86	102	.03199	C
		PETERSON	71%	EPICHLOROHYDRIN	7.233	1.99%	8.145	36	47	65	.06459	C
45	NITROPHENOL		100%	PHENOL NITRATION	1.837	3.49%	2.258	73	42	46	.05249	B
46	CYCLOHEXANE	BLACKBURN	84%	BENZENE HYDROGENATION	1.228	6.53%	1.796	78	44	70	.00072	D
		BLACKBURN	16%	PETROLEUM DISTILLATION								
47	BISPHENOL A		100%	PHENOL/ACETONE	.841	10.99%	1.574	87	45	54	.00199	A
48	CELLULOSE ACETATE		100%	CELLULOSE ESTERIFICATI*	7.897	.49%	8.137	37	59	56	.01099	B
49	CA PROLACTAM	BLACKBURN	100%	CYCLOHEXANONE	3.541	5.49%	4.882	55	53	66	.00453	A
50	PENTAERYTHRITOL		100%	FORMALDEHYDE/ ACETALDEHYDE	1.809	2.99%	2.160	75	57	36	.01719	A
51	NONYL PHENOL		100%	PHENOL ALKYLATION	.511	3.49%	.628	104	50	75	.00655	A
52	ACRYLAMIDE		100%	ACRYLONITRILE	.122	8.49%	.199	126	52	92	.00239	A
53	DIETHYLENE, TRIETHYLENE GLYCOLS	LAWSON	100%	COPRODUCTS W/ ETHYLENE GLYCOL	1.157	5.99%	1.641	85	55	81	.00319	A
54	FUMARIC ACID		100%	MALEIC ACID/ SOMERIZATION	.398	1.99%	.437	113	54	95	.01149	B
55	PROPYLENE GLYCOLS (MONO, DI, TRI)		100%	PROPYLENE OXIDE HYDRATION	6.507	7.49%	10.043	29	75	50	.01258	A
56	EPICHLOROHYDRIN	PETERSON	100%	ALLYL CHLORIDE/ HCI	1.621	2.49%	1.880	77	60	88	.00286	A
57	ALLYL CHLORIDE	PETERSON	100%	PROPYLENE CHLORINATION	8.963	4.99%	12.012	25	95	74	.02699	A
58	ADIPONITRILE/HMDA	DYLEWSKI	11%	ACRYLONITRILE								
		DYLEWSKI	24%	ADIPIC ACID								
		DYLEWSKI	65%	BUTADIENE	8.336	4.99%	11.171	26	101	78	.01499	B
59	TRICHLOROETHYLENE	STANDIFER	9%	ACETYLENE								
		STANDIFER	91%	ETHYLENE	1.486	-8.00%	.901	96	67	82	.00538	A
60	METHYL ISOBUTYL KEYTONE (MIBK)		100%	MESITYL ALCOHOL	8.354	-6.00%	5.763	48	82	41	.04229	A
61	PYRIDINE		100%	FORMALDEHYDE/ ACETALDEHYDE	.727	2.99%	.868	97	69	67	.01499	B
62	BENZENE		80%	NOT IN PROJECT SCOPE								
			20%	TOLUENE HYDRODEALKYL*	.326	.21%	.331	122	68	105	.00010	A

TABLE I

SURVEY AND RANKINS PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	1982 GROSS NMHC EMISSIONS RANK	1982 TOXICITY SCORE RANK EXPON.	1982 TOXICITY SCORE RANK LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
63	ETHANOL (ETHYL ALCOHOL)		100%	ETHYLENE	5.759	2.49%	6.679	44	91	57	.00384	A
64	UREA	STANDIFER	100%	NH3/CO2	5.386	5.69%	7.512	38	99	59	.00065	A
65	ACETALDEHYDE	LOVELL	0%	ETHANOL OXIDATION	1.649						.00999	B
		LOVELL	100%	ETHYLENE	5.488	4.80%	7.271	41	93	77	.00586	A
66	ISOPRENE		67%	C4 HYDROCARBONS								
			33%	SIOAMYLENE EXTRACTION	.246	11.99%	.486	107	70	85	.00218	A
67	FURFURAL		100%	POLY SACCHARIDES HYDROLYSIS	2.341	1.99%	2.636	69	76	79	.01499	B
68	GLYCOL ETHERS	LOVELL	97%	ETHYLENE OXIDE	.321	5.99%	.455	112	72	99	.00058	A
		LOVELL	3%	PROPYLENE OXIDE	.009	5.99%	.014	163	166	165	.00058	A
69	DINITROTOLUENE		100%	TOLUENE DINITRATION	.920	10.99%	1.721	83	79	87	.00175	A
70	SEC-BUTANOL		100%	BUTYLENES	2.426	6.79%	3.601	62	84	72	.00699	B
71	LINEAR ALKYL BENZENE	PETERSON	100%	BENZENE ALKYLATION	.068	1.99%	.077	143	78	126	.00009	A
72	ACROLEIN	PETERSON	100%	PROPYLENE OXIDATION	4.942	3.99%	6.127	46	107	90	.07449	B
73	DIPHENYLAMINE		100%	ANILINE AMINATION	.039	4.99%	.053	151	85	127	.00099	B
74	METHYL STYRENE		15%	CUMENE DEHYDROGENAT*								
			85%	CUMENE PROCESS BY-PRODUCTE	.272	5.99%	.386	117	89	103	.00521	A
75	ETHYLENE DIAMINE/ TRIETHYLENE TETRAMINE		100%	EDC AMMONOLYSIS	.131	4.99%	.176	130	88	112	.00099	B
76	ETHYL ACRYLATE	BLACKBURN	61%	ACETYLENE (REPPE)	1.098	7.99%	1.742	81	136	114	.00609	B
		BLACKBURN	39%	DIRECT ESTERIFICATI*	1.093	7.99%	1.734	82	104	91	.00949	B
77	METHYL CHLORIDE	STUEWE	2%	METHANE CHLORINATION	.189	-3.26%	.155	135	102	131	.01699	B
		STUEWE	98%	METHANOL HYDROCHLORIN*	.975	3.67%	1.210	93	106	100	.00269	A
78	METHYLENE DIPHENOL DIISOCYANATE (*		100%	DPMDA/PHOSGENE	.089	10.99%	.168	134	94	118	.00023	A
79	N-BUTYRALDEHYDE		100%	OXO PROCESS	1.927	4.24%	2.346	72	109	89	.00243	A
80	NITROANILINE		100%	NITRO CHLOR BENZENE	.071	.00%	.071	144	97	122	.00599	B
81	ACETOPHONE		60%	CUMENE PEROXIDATION	.134	5.99%	.191	128	98	116	.00521	A
			40%	ETHYL BENZENE OXIDATION								

TABLE I

SURVEY AND RANKING PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	RANK	1982 TOXICITY SCORE RANK EXPON.	LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
82	ISOPHTHALATE ACID		100%	M-XYLENE OXIDATION	.235	11.99%	.465	110	100	98	.00199	B
83	BENZOIC ACID		100%	TOLUENE AIR OXIDATION	.279	4.99%	.375	118	105	96	.00199	B
84	DIISOOCTYL PHTHALATE (DI2-ETHYLHEXYL)		100%	PHTHALATE ANHYDRIDE/ ALCOHOL	.593	6.19%	.851	99	103	109	.00199	B
85	2-ETHYL 1-HEXANOL		100%	ALDO COND./OXO	1.130	7.99%	1.794	79	117	94	.00252	A
86	N-BUTANOL (BUTYL ALCOHOL)		20%	ACETALDEHYDE								
			80%	OXO PROCESS	1.265	3.99%	1.601	86	120	97	.00252	A
87	PROPIONIC ACID		7%	OTHERS								
			93%	OXO PROCESS	.424	6.99%	.637	103	115	93	.00599	B
88	ETHYL ACETATE	KEY	100%	ACETIC ACID	1.077	1.99%	1.213	92	121	101	.00499	B
89	ETHYLENE DIBROMIDE		100%	ETHYLENE BROMINATION	1.508	-3.00%	1.256	91	119	107	.00749	B
90	ACETONE CYANOHYDRIN	BLACKBURN	100%	ACETONE CYANATION	.283	8.49%	.462	111	110	117	.00051	A
91	BENZYL CHLORIDE		100%	TOLUENE CHLORINATION	.134	3.99%	.170	131	116	108	.00149	B
92	DICHLOROPHENOL		45%	PHENOL CHLORINATION	.009	2.99%	.011	165	118	152	.00099	B
			55%	TRICHLOROBENZE*	.219	2.99%	.261	124	134	135	.01896	A
93	ISOBUTYRALDEHYDE		100%	OXO PROCESS	.941	2.99%	1.123	94	128	106	.00252	A
94	CRESYLIC ACIDS (SYN)		4%	CYMENE OXIDATION								
			80%	NATURAL COAL TAR								
			8%	PHENOL/METHANOL	.013	4.99%	.018	161	123	149	.00099	B
			8%	TOLUENE SULFONATION	.013	4.99%	.018	162	130	148	.00099	B
95	N-N DIMETHYL ANILINE		100%	ANALINE AMINOLYSIS	.039	4.99%	.053	150	111	132	.00199	B
96	ACETYLENE		30%	CALCIUM CARBIDE								
			8%	ETHYLENE BY-PRODUCT								
			62%	HYDROCARBON OXIDATION	1.779	.00%	1.779	80	133	113	.00580	A
97	PHOSGENE		100%	CO/CI2	.146	9.99%	.259	125	114	129	.00017	A
98	T-BUTANOL		21%	ISOBUTYLENE	.167	.07%	.168	133	160	156	.00049	B
			79%	PROPYLENE OXIDE CO-PRODUCT	.556	8.36%	.901	95	126	119	.00070	A
99	SALICYLIC ACID		100%	SODIUM PHENATE	.023	1.99%	.027	160	112	137	.00049	B
100	DIMETHYL HYDRAZINE		100%	NITROSODIMETHYL AMINE	.001	4.99%	.00268	173	113	164	.00049	B
101	DODECENE		100%	MONENE COPRODUCT	1.444	.99%	1.533	88	135	120	.00499	B

TABLE I

SURVEY AND RANKING PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	RANK	1982 TOXICITY SCORE RANK EXPON.	LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
102	DIISOLDCYL PHTHALATE		100%	PHTHALATE ANHYDRIDE/ ISODECANOL	.286	3.49%	.351	121	124	133	.00199	B
103	BUTYL ACRYLATE	BLACKBURN	100%	ACRYLIC ACID ESTERIFICAION	.410	7.99%	.651	102	132	111	.00199	B
104	CHLOROSULFONIC ACID		100%	SO3 HYDROCHLORIN*	.344	1.99%	.388	116	129	125	.00249	B
105	METHYL ETHYL KEYTONE (MEK)	KEY	25%	BUTANE OXIDATION								
		KEY	75%	SEC-BUTANOL	.321	4.99%	.430	114	139	115	.00099	B
106	ISOBUTANOL (ISOBUTYL ALCOHOL)		100%	OXO PROCESS	.442	2.99%	.528	106	138	121	.00252	A
107	HYDROQUINONE		100%	ACETONE COPRODUCT	.037	.00%	.037	155	131	139	.00149	B
108	MONO. DI. TRI. METHYL AMINES		100%	METHANOL AMMONOLYSIS	.238	6.99%	.358	120	143	124	.00099	B
109	ADIPIC ACID	BLACKBURN	100%	CYCLOHEXANE	.325	4.06%	.412	115	147	123	.00026	A
		BLACKBURN	0%	PHENOL								
110	CHLORONITROBENZE*		100%	CHLOROBENZENE NITRATION	.173	1.99%	.195	127	141	136	.00164	B
111	CARBON DISULFIDE		100%	METHANE SULFUR VAPOR	.081	2.99%	.097	140	140	143	.00015	A/C
112	BIPHENYL		100%	TOLUENE HYDRODEALKYL*	.006	.00%	.00625	170	137	166	.00010	A
113	ACETYL CHLORIDE		100%	SODIUM SCETATE	.039	4.99%	.053	149	144	138	.00099	B
114	MONO. DI. TRI. ETHYL AMINE		100%	ETHANOL AMMONOLYSIS	.074	5.99%	.106	139	145	144	.00099	B
115	CHLOROACETIC ACID		100%	ACETIC ACID CHLORONATION	.072	1.99%	.081	141	146	147	.00099	B
116	BENZOPHENONE		100%	BENZENE/CARBON TET	.001	4.99%	.00241	172	142	171	.00149	B
117	METHYL BROMIDE		100%	METHANOL/HBR	.017	6.99%	.027	159	148	159	.00049	B
118	PROPYL ALCOHOL		87%	OXO PROCESS	.072	7.99%	.114	138	155	142	.00103	A
			13%	PROPANE OXIDATION	.025	7.99%	.041	154	169	163	.00249	B
119	BUTYL AMINC		100%	BUTYRALDEHYDE HYDROGEN*T*N	.125	2.99%	.150	136	153	141	.00599	B
120	ETHYL (DIETHYL) ETHER		100%	ETHANOL	.179	.00%	.179	129	152	145	.00299	B
121	PROPYL AMINES (M-D-T)		50%	N-PROPYL ALCOHOL	.056	.99%	.060	146	163	154	.00599	B
			50%	N-PROPYL CHLORIDE	.056	.99%	.060	147	164	155	.00599	B
122	CROTONALDEHYDE		100%	ALDO PROCESS	.009	3.99%	.012	164	154	150	.00049	B
123	ISOOCTYL ALCOHOL		100%	OXO PROCESS/ HYDROGENATION	.143	-3.50%	.116	137	157	146	.00099	B

TABLE I

SURVEY AND RANKING PROCESS STUDIES

SEL. RANK NO.	CHEMICAL NAME	ASSIGNED TASK LEADER	1982 % OF TOTAL PROD.	PROCESS USED	1976 GROSS NMHC EMISSIONS M LBS	PERCENT GROWTH	1982 GROSS NMHC EMISSIONS M LBS	RANK	1982 TOXICITY SCORE RANK EXPON.	LINEAR	EMISSION FACTOR LB/LB	EMISSION FACTOR SOURCE
124	FORMIC ACID	KEY	98.*	N-BUTANE OXIDATION	.027	3.99%	.035	156	151	162	.00049	B
		KEY	1.5%	OTHERS								
125	ETHYLENE GLYCOL ME ETHER ACETATE		100%	ETHOXY ETHANOL ESTER	.046	4.99%	.062	145	156	153	.00049	B
126	LINEAR ALKYL SULFONATE		100%	LAB SULFONATION	.050	1.99%	.056	148	158	158	.00007	A
127	ISODECANOL		25%	N-PARAFFIN OXIDATION								
			75%	OXO PROCESS	.058	4.99%	.078	142	165	151	.00099	B
128	ALLYL ALCOHOL	PETERSON	47%	ALLYL CHLORIDE HYDROLYSIS								
		PETERSON	6%	PROP GLYCOL DEHYDRATION								
		PETERSON	47%	PROP OXIDE ISOMERIZATION	.009	1.99%	.010	166	159	160	.00025	A
129	ISOPROPYL ACETATE		100%	ISOPROPANOL ESTERIFICATI*	.039	4.99%	.053	152	162	157	.00099	B
130	METHYL ACETATE		100%	ACETIC ACID/ METHANOL	.029	1.99%	.033	157	167	161	.00199	B
131	CYCLOOCTADIENE		100%	BUTADIGNE DIMERIZATION	.030	6.99%	.045	153	161	167	.00149	B
132	HEXACHLOROBENZENE		100%	HEXACHLOROCYCL*	.001	1.99%	.00180	176	168	173	.00049	B
133	N-BUTYL ACETATE		100%	ESTERIFICATION	.008	1.49%	.00984	167	171	168	.00007	A
134	BUTYRIC ACID		33%	BUTYRALDEHYDE OXIDATION								
			67%	N-BUTANE OXIDATION	.005	4.99%	.00732	169	174	172	.00135	A
135	DINITROPHENOL		100%	DNC BENZENE HYDROLYSIS	.001	4.99%	.00201	174	173	175	.00149	B
136	AMINO ETHYLETHANSLAM*		100%	ETHYLENEDIAMIN*	.007	2.99%	.00888	168	175	170	.00123	A
137	CYCLOHEXYLAMINC		50%	ANILINE								
			50%	CYCLOHEXANONE	.003	4.99%	.00469	171	172	174	.00049	B
138	TOLUENE SULFONIC ACIDS		100%	TOLUENE SULFONATION	.002	.00%	.00233	175	176	176	.00012	B
139	BENZYL BENZOATE		50%	BENZALDEHYDE	.000	4.99%	.00093				.00099	B
			50%	BENZYL ALCOHOL/ ACID	.000	4.99%	.00093				.00099	B
140	BENZOYL CHLORIDE		100%	BENZOIC ACID	.000	4.99%	.00010				.00004	B

Source Codes: A - State EIQ's; B - Monsanto Research Corp./Radian; C - Houdry; D - HI Site Visits;

E - Product Report

TABLE II
SURVEY AND RANKING PROCESS STUDIES

Selection Ranking No.	Chemical	1982 % of Total Production	Process	Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
1	Acrylonitrile	* 100%	Amoxidation																	A																					
2	Ethylene Dichloride	* 50%	Direct chlorination		A																																				
		* 50%	Oxychlorination																		A																				
		-	Acetylene																			A																			
3	Ethylene Oxide	* 66%	Air Oxidation ethylene	A																																					
		* 34%	O_2 Oxidation ethylene	A																																					
4	Ethylbenzene	* 98%	Benzene alkylation										A																												
		2%	Mixed xylene extraction (not in scope)																																						
5	Ethylene	* 100%	Cracking				A																																		
6	Vinyl Chloride	99%	Ethylene dichloride							A																															
		1%	Acetylene																		A																				
7	Dimethyl Terephthalate	* 25%	Hercules	A		B		C																																	
		35%	DuPont	A		B		C																																	
		* 23%	Amoco via TPA	A		B																																			
		* 17%	Eastman via TPA	A		B		C																																	
8	Maleic Anhydride	* 85%	Benzene oxidation	A																																					
		* 15%	Butane oxidation	A																																					
9	Propylene Oxide	* 60%	Chlorohydrin																												A										
		* 40%	Peroxidation																				A																		
10	Methyl Methacrylate	* 100%	Acetone cyanohydrin					D				A							B						C							E									
11	Formaldehyde	* 77%	Silver catalyst high methanol	A													B																								

*Processes assigned for study

REACTION MODULES **

** Letter indicates the order of occurance.

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

				REACTION MODULES																																					
Selection Ranking No.	Chemical	1982 % of Total Production	Process	Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
		23%	Low methanol	A																																					
12	Nitrobenzene	* 100%	Benzene nitration																														A								
13	Cyclohexane	* 84%	Benzene			A																																			
		16%	Petroleum distillation (not in scope)																																						
14	Acrylic Acid	* 77%	Propylene oxidation	A																																					
		23%	Modified Repp																					A																	
15	Phenol	* 93%	Cumene	A																						B															
		3%	Benzene chlorination		A														B								C														
		2%	Toluene oxidation	2A																																					
		2%	Benzene sulfonation									A			B												D							C							
16	Methanol	* 100%	Methane																						A										B						
17	1,1,1 Trichloroethane	* 74%	Vinyl chloride		A																																				
		16%	Vinylidene chloride																				A																				
		10%	Ethane		A																																				
18	Acetic Acid	* 33%	Acetaldehyde	A																																					
		* 44%	Butane oxidation	A																																					
		* 19%	Methanol-CO																					A																	
		4%	Others																																						
19	Ethylene Glycol	* 100%	Ethylene oxide						A																																
20	Terephthalic Acid	14%	Mobil	A		B																																			
		* 47%	Eastman	A		B																																			
		* 39%	Amoco	A		B																																			

*Processes assigned for study

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

Selection Ranking No.	Chemical	1982 % of Total Production	Process	REACTION MODULES																																					
				Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
21	Styrene	* 100%	Ethylbenzene				A																																		
22	Chloroprene	100%	Butadiene		A																																				
23	Acetic Anhydride	* 100%	Acetic acid	A																																					
24	Cyclohexanol/Cyclohexanone	* 75%	Cyclohexane	A																																					
		25%	Phenol			A																																			
25	Allyl Chloride	100%	Propylene Chlorination		A																																				
26	Adiponitrile/HMDA	65%	Butadiene		A	B																																			
		24%	Adipic acid								A					B																									
		11%	Acrylonitrile																															A					
27	Carbon Tetrachloride	* 38%	CS_2		A																																				
		* 42%	HC Chlorination		A		B																																
		* 20%	Methane		A										B																										
28	Vinyl Acetate	* 72%	Ethylene vapor phase																									A													
		15%	Ethylene liquid phase																									A													
		13%	Acetylene vapor phase																																	A				
29	Methylene Chloride	* 61%	Methanol		A																																				
		* 39%	Methane		A																																				
30	Acetone	* 60%	Cumene	A																						B															
		40%	Isopropanol (two separate processes)	A													A																								
31	Methyl Chloride	* 97%	Methanol		A																																				
		* 3%	Methane		A																																				

*Processes assigned for study

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

Selection Ranking No.	Chemical	1982 % of Total Production	Process	REACTION MODULES																																					
				Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
32	Glycerol	71%	Epichlorohydrin		A				C	B																															
		15%	Allyl alcohol						B														A																		
		* 14%	Acrolein			A			C														B																		
33	Urea	100%	NH_3/CO_2								A					B																									
34	Acetaldehyde	* 100%	Ethylene	A																																					
			Ethanol oxidation	A																																					
35	Toluene Diisocyanate	100%	Diaminotoluene																										A												
36	Ethyl Chloride	96%	Ethylene																			A																			
		4%	Ethanol/ethane		A																																				
37	Cumene	* 100%	Benzene										A																												
38	Chlorobenzene	* 100%	Benzene		A										B																										
39	Hydrogen Cyanide	50%	Andrussow process																	A																					
		50%	Acrylonitrile by-product																	A																					
40	Fluorocarbons	100%	CCl_4/C_2Cl_6 Fluorination																																			A			
41	Perchloroethylene	* 66%	Ethylene dichloride																		A																				
		* 34%	HC Chlorination		A		B																																		
			Acetylene		A																																				
42	Butadiene	* 80%	Ethylene co-product				A																																		
		* 13%	n-butane				A																																		
		* 7%	n-butenes				A																																		
43	Acrolein	* 100%	Propylene	A																																					

*Processes assigned for study

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

				REACTION MODULES																																					
Selection Ranking No.	Chemical	1982 % of Total Production	Process	Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
44	Ethanol	100%	Ethylene						A																																
45	Chloroform	* 61%	Methane		A																																				
		* 39%	Methanol		A																																				
46	Ethanolamines	100%	Ethylene oxide								A																														
47	2-Ethyl Hexanol	100%	Oxo											A																											
48	Vinylidene Chloride	* 50%	1,1,1 Trichloroethane							A																															
		* 50%	1,1,2 Trichloroethane							A																															
49	Alkyl Leads	95%	Ethyl chloride										A																												
		5%	Electrolysis																																						
50	Isopropanol	100%	H_2SO_4 hydration of propylene						B			A																											
51	Phthalic Anhydride	70%	o-xylene	A																																					
		30%	Napthalene	A																																					
52	Methyl Isobutyl ketone	100%	Mesityl alcohol			A										C		B																							
53	Pentaerythritol	100%	HCHO/Acetaldehyde															A																							
54	Sec butanol	100%	Butylenes						B			A																											
55	Bisphenol A	100%	Phenol acetone															A																							
56	Trichloroethyene	* 91%	Ethylene		A					B																															
		9%	Acetylene							B																															
57	n-butyraldehyde	100%	OXO process											A																											
58	di/tri ethylene glycol	100%	Ethylene glycol co-products					B	A																																

*Processes assigned for study

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

Selection Ranking No.	Chemical	1982 % of Total Production	Process	REACTION MODULES																																					
				Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
59	Epichlorohydrin	* 100%	Allyl chloride chlorohydrination							A																															
60	Nonyl Phenol	100%	Phenol alkylation										A																												
61	Ethyl acrylate	39%	Direct esterification					A																																	
		61%	Acetylene																					A																	
62	Ethylene dibromide	100%	Bromination of ethylene																																				A		
63	Acetylene	62%	Natural gas				A																																		
		30%	Calcium carbide (not in scope)																																						
		8%	Ethylene co-product				A																																		
64	n-butanol	80%	OXO process											A																											
		20%	Acetaldehyde			B												A																							
65	t-butyl alcohol	70%	Propylene oxide by-product	A																																					
		30%	Isobutylenes									A							B																						
66	Isoprene	33%	Isoamylene extraction														A																								
		67%	C_4's (not in scope)																																						
67	Glycol ethers	* 97%	Ethylene oxide																											A											
		3%	Propylene oxide																											A											
68	Isophthalic acid	100%	m-xylene oxidation	A																																					
69	Ethyl acetate	100%	Acetic acid					A																																	
70	Methyl ethyl ketone	75%	Sec butanol														A																								
		25%	Butane oxidation	A																																					

*Processes assigned for study

TABLE II
(Continued)

SURVEY AND RANKING PROCESS STUDIES

Selection Ranking No.	Chemical	1982 % of Total Production	Process	REACTION MODULES																																					
				Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrobromination
71	Benzoic acid	100%	Toluene oxidation	A																																					
72	Adipic acid	100%	Cyclohexane	2A																																					
73	Benzene	28%	Hydrodealkylation of toluene																																					A	
		72%	Not in project scope																																						
74	Ethylene diamine	100%	EDC ammonolysis								A																														
75	Methyl amines	100%	Methanol ammonolysis								A																														
76	Isobutyl alcohol	100%	OXO process											A																											
77	Phosgene	100%	Carbon monoxide chlorination		A																																				
78	Diisodecyl phthalate	100%	Phthalic anhydride, isodecanol					A							B																										
79	Isobutyraldehyde	100%	OXO process											A																											
80	Methylene diphenyl	100%	Diphenyl methane diamine/phosgene																										A												
81	Benzyl Chloride	100%	Toluene chlorination		A																																				
82	Diethyl ether	100%	Ethanol based													A																									
83	Linear alkyl benzene	* 100%	Benzene										A																												
84	Ethyl amines	100%	Ethanol ammonolysis								A																														
85	Chloroacetic acid	100%	Acetic acid chlorination		A																																				
86	Linear alkyl sulfonates	100%	LAB sulfonation		A							B			C																										
87	Formic acid	98.5%	Butane oxidation	A																																					
		1.5%	Others																A																						
88	Methyl bromide	100%	Hydrobromination of methanol																																						A

TABLE II
(Continued)

Rank No.	Chemical	Process	REACTION MODULES																																						
			Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrofluorination	Isomerization
89	Propylene glycols	Propylene oxide hydration						A																															
90	Caprolactam	Cyclohexanone																																					A
91	Dinitrotoluene	Toluene dinitration																												2A									
92	Fumaric acid	Maleic acid isomerization																																					A
93	Diisoctyl phthalate	Phthalic anhydride					A																																
94	Propionic acid	Oxo process											A																										
		LPG oxidation	A																																				
95	Acetone cyanohydrin	Acetone/HCN																											A										
96	Acrylamide	Acrylonitrile															A																						
97	Methyl styrene	Cumene byproduct													A																								
		Others																																					
98	Chloronitrobenzenes	Chlorobenzene																												A									
99	Carbon disulfide	Thacker process																																					
100	Diphenyl	Toluene/Benzene																																			A		
101	n-butyl acetate	Butanol/acetic acid					A																																
102	Benzophenone	Benzone/carbon tetrachloride										A						B																					
103	Benzyl benzoate	Benzaldehyde	A				B																A																
		Benzyl alcohol					A																																

TABLE II
(Continued)

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Rank No.	Chemical	Process	Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	Hydrofluorination	Isomerization
			REACTION MODULES																																						
104	Aminoethylethanolamine	Ethylene oxide								A																															
105	Chlorosulfuric acid	(Chlorobenzene)																			A																				
106	Dimethylhydrazine	Dimethylamine	A																																						
107	n-dimethyl aniline	Aniline/methanol																											A												
108	Hexachlorobenzene	Hexachlorocyclohexane		A																																					
109	Methyl acetate	Acetic acid					A																																		
110	n-propyl alcohol	Propion aldehyde			C								A				B																								
111	Salicylic acid	Sodium phenate																					A			B															
112	Diphenylamine	Aniline																															A								
113	Acetophenone	Cumene	A																						B																
		Ethylbenzene	A													B																									
114	Acetyl chloride	Sodium acetate		A																																					
115	Propylene	Naptha/gas oil				A																																			
		Natural gas/liquids				A																																			
		Refinery byproduct																																							
116	Aniline	Nitrobenzene hydrogenation			A																																				
117	Furfural	Polysaccharides hydrolysis																A																							
118	Butyl amines	Butyraldehyde hydrogenation			A					A																					A										

TABLE II
(Continued)

Rank No.	Chemical	Process	REACTION MODULES																																						
			Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	[illegible]	Isomerization
119	Allyl alcohol	Allyl chloride hydrolysis																A																							
		Propylene glycol dehydration													A																										
		Propylene oxide isomerization																																							A
120	Pyridine/picoline	Formaldehyde/acetaldehyde								A																															
121	Cyclohexyl amine	Aniline			A																																				
		Cyclohexanone								A																															
122	Cresylic acids	Phenol methanol										A																													
		Toluene sulfonation									A																						B								
		Cymene oxidation	A																																						
		Natural coal tar																																							
123	Crotonaldehyde	Aldo process													B															A											
124	Hydroquinone	Acetone coproduct	A																						B																
125	Isodecanol	Oxo process			B								A																												
		n-paraffin oxidation	A																																						
126	Isooctyl alcohol	Oxo process			B								A																												
127	Cellulose acetate	Cellulose esterification					A											B																							
128	Isopropyl acetate	Isopropanol					A																																		
129	Cyclooctadiene	Butadiene																																	A						

TABLE II
(Continued)

Rank No.	Chemical	Process	REACTION MODULES																																						
			Oxidation	Chlorination	Hydrogenation	Pyrolysis	Esterification	Hydration	Dehydrochlorination	Ammonolysis	Sulfonation	Alkylation	Hydroformulation	Neutralization	Dehydration	Dehydrogenation	Condensation	Hydrolysis	Ammoxidation	Oxychlorination	Hydrochlorination	Peroxidation	Carbonolation	Reduction	Cleaving	Acidification	Oxyacetylation	Phosgenation	Alcoholysis	Saponification	Hydrocyanation	Nitration	Fusion	Reforming	Hydrodimerization	Addition Ester	Fluoronation	Bromination	Hydrodealkylation	[illegible]	Isomerization
130	Dinitrophenol	DNC benzene																A																							
131	Dichlorophenol	Phenol chlorination							A																																
132	Butyl acrylate	Acrylic acid					A																																		
133	Propyl amines	n-propanol								A																					A										
		n-propyl chloride								A																															
134	Dodecene	Nonene coproduct																																							A
135	Nitro aniline	Nitrochlorobenzene																														A									
136	Nitrophenol	Phenol nitration												B																		A									
137	Ethylene glycol MEE Acetate	Ethoxy ethanol					A																																		
138	Butyric acid	Butyraldehyde	A																																						
		Butane oxidation	A																																						
139	Toluene sulfonic acid	Toluene									A																														
140	Benzoyl chloride	Benzoic acid																																							

TABLE III

No.	Product	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
			Process Modules *													
1.	Acrylonitrile	SOHIO Amoxidation	5	1										1		
2.	Ethylene dichloride	Ethylene oxychlorination	3	1	1									1		
3.	Dimethylterephthalate	p-xylene oxidation	1		2			4	2							
4.	Vinyl chloride	Ethylene dichloride dehydrochlorination	6	1												
5.	Ethylene oxide	Ethylene oxidation	3	2												1
6.	Ethyl benzene	Benzene alkylation	5													
7.	Styrene	Ethyl benzene dehydrogenation	6									1				
8.	Maleic anhydride	Benzene oxidation	1	2			2	1				1	1			
9.	Propylene oxide	Proplyene chlorohydrin	3		1							1				
10.	Vinyl acetate	Ethylene vapor phase	9	1	2											
11.	Methyl methacrylate	Acetone hydrocyanation	4						1							
12.	Formaldehyde	Silver catalyst high methanol	1	2	1										2	1
13.	Ethylene	Hydrocarbon pyrolysis	8	1					1					1		
14.	1,3 butadiene	Hydrocarbon pyrolysis	10	1		2	1							2		
15.	Acrylic acid/esters	Propylene oxidation	4	1		1								1		
16.	Cyclohexane	Benzene hydrogenation	1									1				
17.	Acetic acid	Butane oxidation	7	1	1											
18.	Methanol	High pressure methane synthesis	2									1				
19.	1.1,1 trichloroethane	Vinylidene chloride chlorination	5	1												
20.	Trichloroethylene	EDC dehydrochlorination	3						1							
21.	Methylene chloride	Methyl chloride chlorination	2		2											
22.	Carbon tetrachloride	Methane chlorination	4						1			3				
23.	Phenol	Cumene	9		1											
24.	Acetone	Cumene	9		1											

*Number indicates the number of units associated with the process.

TABLE III
(Continued)

No.	Product	Process	Process Modules													
			Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
25.	Chloroform	Methane chlorination	2		1				1							
26.	Methyl chloride	Methanol chlorination	2		2											
27.	Nitrobenzene/aniline	Benzene nitration	3		1	1						2				
28.	Ethylene glycol	Ethylene oxide hydration	3				3		1							
29.	Glycerol	Allyl chloride - edichlorohydrin	7		2	1										
30.	Adiponitrile/HMDA	Butadiene chlorination	1													
31.	Chloroprene	Butadene chlorination	3	1			3									
32.	Cyclohexanol/cyclohexanone	Cyclohexane oxidation	5		2											
33.	Acetaldehyde	Ethylene oxidation	2		1							1		1		
34.	2 ethyl 1 hexanol	n-butryaldehyde aldol condensation	2						1							
35.	Toluene diisocyanate	Amine phosgenation	4													
36.	Chlorobenzene	Benzene chlorination	4	2				1								
37.	Ethyl acrylate	Acrylic acid esterification	4						1							
38.	Linear alkyl benzenes/sulfonates	Alkyl benzene sulfonation	2					1	1		1	2		1		
39.	Acrolein	Propylene oxidation	3													
40.	Ethyl chloride	Ethylene/HCl	3		1											
41.	Methyl isobutyl ketone	Acetone dehydration	5	1								3				
42.	Acetylene	Methane partial oxidation	8	4	3											
43.	Lead alkyls	Sodium/lead alloying with ethyl chloride	2		2											

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
			Process Modules													
44	Terephthalic acid	Eastman	2		1			2	2				3			1
		Mobil														
		Amoco	1	1				4	3							
45	Acetic anhydride	Acetic acid	4		1											
46	Allyl chloride	Propylene	3	2					1			1				
47	Vinyl acetate	Ethylene vapor	8		2							3			1	
		Ethylene liquid														
		Acetylene	3													
48	UREA	Ammonia/carbondioxide	2	1				1					1			
49	Cumene	Benzene alkylation	2													
50	Caprolactam	Cyclohexanone	2			1										1
51	Hydrogen cyanide	Andrussow process	2		3											
		Acrylonitrile byproduct														
52	Fluorocarbons	CCL_4/CH_3CL_3 Fluorination	3	1	1				3			1				
53	Ethanol	Ethylene	4	1	3							2				
54	Ethanolamines	Ethylene oxide	4	1												
55	Vinylidene chloride	1,1,1 Trichloroethane														
		1,1,2 Trichloroethane														
56	Isopropanol	Propylene/H_2SO_4	2	1	1											1
57	Perchloroethylene	Ethylene dichloride	4		1				2			3				
		Methane chlorination	3													

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
			Process Modules													
58	Sec-butanol	Butylenes	2		2											1
59	Phthalic anhydride	o-xylene	3					1					1			
		Napthalene	2		1			1					1			
60	Pentaerythritol	HCHO/Acetaldehyde				1		1	1				1			
61	Bisphenol A	Phenol/acetone	1		2				1				1	1		
62	n-butyraldehyde	Oxo process	6									1				
63	Epichlorohydrin	Allyl chloride	2													
64	Di/triethylene glycols	ethylene glycol	2													
65	Dinitrotoluene	Toluene dinitration	1		1		1						1			
66	Nonyl phenol	Phenol alkylation	2								1					
67	Fumaric acid	Maleic acid isomer						2		1		1				
68	Diisooctyl phthalate	Phthalic anhydride	2		1								1			
69	Ethylene dibromide	Ethylene bromination	2		2											
70	n-butanol	Oxo process	6									1				
		Acetaldehyde	2		2							1				1
71	Tert-butanol	Propylene oxide														
		Isobutylenes	2													1
72	Propylene glycols	Propylene oxide	2				2									
73	Glycol ethers	Ethylene oxide	4													
74	Isoprene	Isoamylene extraction	2	1												
		CH_4 Hydrocarbons														

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
			Process Modules													
75	Isophthalic acid	m-xylene oxidation	1		1							1	1			
76	Ethyl acetate	Acetic acid	3								2	1				
77	Propionic acid	Oxo process														
		LPG oxidation														
78	Acetone cyanohydrin	Acetone/HCN	2				2						1			
79	Benzoic acid	Toluene oxidation	5	1	3						1	1	1			
80	Methyl ethyl ketone	Sec-butanol	2		1							2				
		Butanol oxidation	3									2				
81	Adipic acid	Cyclohexane	1					1	1	1	1					
		Phenol	1					1	1	1	1					
82	Benzene	Toluene hydrodealkylation	3	1								1				
		Not in Scope														
83	Acrylamide	Acrylonitrile						1					1		1	
84	Methyl styrene	Cumene byproduct	2													
		Others														
85	Ethylene diamine	EDC ammonolysis	3													
86	Diphenyl methane diisocyanate	Diamide/phosgene	2									1				
87	Phosgene	CO/Cl_2			2											
88	Methylamines	Methanol ammonolysis	6		1							1				
89	Isobutanol	Oxo process	6									1				

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
			Process Modules													
90	Diisodecyl phthalate	Toluene	2		1							1				
91	Isobutyraldehyde	Oxo process	6									1				
92	Benzyl chloride	Toluene chlorination	2								1					
93	Chloronitrobenzenes	Chlorobenzene	1					2								
94	Diethyl ether	Ethanol	2		1											
95	Ethylamines	Ethanolammonolysis	4													
96	Carbon disulfide	Methane/sulfur	3		2											
97	Chloroacetic acid	Acetic acid						1	1				1			
98	Formic acid	Butane oxidation	2		1											
		Others	2									1				
99	Biphenyl	Toluene/benzene	3	1								1				
100	n-butyl acetate	Butanol/acetic acid	2								1	1				
101	Methyl bromide	Methanol hydrobromination	1						1		1					
102	Benzo phenone	Benzene/CCl_4	2	1				1		1						
103	Beyzyl benzoate	Benzaldehyde														
		Benzyl alcohol														
104	Amino ethyl ethanolamine	Ethylene oxide	5	1			1									
105	Chlorosulfonic acid	Chlorobenzene														
106	Dimethyl hydrazine	Dimethyl amine														
107	n-n dimethyl aniline	Aniline/methanol														

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
108	Hexachlorobenzene	Hexachlorocyclohexane														
109	Methyl acetate	Acetic acid/methanol	2		1				1							
110	n-propyl alcohol	Propionaldehyde	4									3				
111	Salicylic acid	Sodium phenate	2		1			1	1				1			
112	Diphenylamine	Aniline	1									1				
113	Acetophenone	Cumeme	4		1			1								
		Ethyl benzene	2			1										
114	Acetyl chloride	Sodium acetate														
115	Propylene	Naptha/gas oil	8	1					1					1		
		Natural gas/liquids	8	1					1					1		
		Refinery byproduct														
116	Aniline	Nitrobenzene hydrogenation	2			1						1				
117	Furfural	Polysacchrides hydrolysis	3						1	1			1			
118	Butylamines	Butyraldehyde	4													
119	Allyl alcohol	Allyl chloride hydrolysis														
		Propylene glycol dehydration														
		Propylene oxide														
120	Pyridine/picoline	HCHO/Acetaldehyde														
121	Cyclohexylamine	Aniline														
		Cyclohexanone														

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
			Process Modules													
122	Cresylic acids	Phenol/methanol	7			1	1					1				
		Toluene sulf	2													
		Cumene oxidation	2													
		Natural coal tar	6		1		1									
123	Crotonaldehyde	Aldo process	4		1							1	1			
124	Hydroquinone	Acetone coproduct	2		1			1					2			
125	Isodecanol	Oxo process	4		2							3				
		n-paraffin oxidation														
126	Cellulose acetate	Esterification	1		1				2		1	2	2			
127	Isopropyl acetate	Isopropanol	4								1	2				
128	Cyclooctadiene	Butadiene	2													
129	Dinitrophenol	DNC Benzene														
130	Dichlorophenol	Phenol chlorination														
131	Butyl acrylate	Acrylic acid	4						1							
132	Propyl amines	n-propanol	4													
		n-propychloride														
133	Dodecene	Nonene coproduct														
134	Nitroaniline	Nitrochlorobenzene														
135	Nitrophenol	Phenol nitration	1	1		1									1	
136	Ethylene glycol MEE acetate	Ethoxy ethanol	1									1				

TABLE III
(Continued)

Rank No.	Chemical	Process	Distillation	Absorption	Scrubbing/Washing	Extraction	Evaporation	Crystallization	Drying	Screening/Settling	Mixing/Blending	Separating	Filtration	Quenching	Ion Exchange	Dilution
137	Butyric acid	Butyraldehyde	1									1				
		Butane oxidation	2	1	1											
138	Toluene sulfonic acid	Toluene														
139	Benzoyl chloride	Benzoic acid														
140	Isooctyl alcohol	Oxo process	4		2											

TABLE IV

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
1.	Acrylonitrile	Propylene Ammoxidation		X	X		X								X	X		
2.	Ethylene Dichloride	Oxychlorination		X	X							X			X	X		
		Direct Chlorination		X	X							X			X	X		
3.	Ethylene Oxide	Air Oxidation/Ethylene					X							X	X	X		
		O_2 Oxidation/Ethylene					X							X	X	X		
4.	Vinyl Chloride	Ethylene Dichloride Acetylene			X							X			X	X		
5.	Ethylene	H C Cracking		X	X										X	X		X
6.	Ethyl Benzene	Benzene Alkylation Mixed Xylenes			X		X								X	X		
7.	Dimethyl Terephthalate	Hercules			X				X						X	X		X
		Dupont			X				X						X	X		X
		Amoco via TPA			X				X						X	X		X
		Eastman via TPA			X				X						X	X		X
8.	Maleic Anhydride	Benzene Oxidation			X				X		X	X			X	X		
		Butane Oxidation																

TABLE IV
(continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption	Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
9.	Propylene Oxide	Chlorohydrin					X							X	X		
		Peroxidation															
10.	Methyl Methacrylate	Acetone Cyanohydrin					X				X			X		X	
11.	Formaldehyde	Silver Catalyst		X	X		X				X				X	X	
		Metal Oxide		X	X		X				X				X	X	
12.	Nitrobenzene/Aniline	Benzene					X										
13.	Acrylic Acid	Propylene Oxidation			X						X			X	X		
		Acetylene (Reppe)			X						X			X	X		
14.	Phenol	Cumene			X									X			
		Benzene Chlorination															
		Toluene Oxidation															
		Benzene Sulfonation															
15.	Cyclohexanol/Cyclohexanone	Cyclohexanone			X		X				X			X	X		
		Phenol															
16.	Methyl Alcohol (Methanol)	Methane	X		X									X			

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
17.	1,1,1 Trichloroethane	Vinyl Chloride	x		x						x						x	
		Vinylidene Chloride																
18.	Ethylene Glycol	Ethylene Oxide			x											x		x
19.	Acetic Acid	Acetaldehyde																
		Butane Oxidation	x		x										x	x		
		Methanol/CO																
		Others																
20.	Terephthalic Acid	Mobil																
		Eastman																
		Amoco																
21.	Styrene	Ethylbenzene					x								x	x		
22.	Chloroprene	Butadiene			x						x				x		x	
23.	Acetic Anhydride	Acetic Acid																
24.	Allyl Chloride	Propylene			x		x				x				x			
25.	Vinyl Acetate	Ethylene Vapor													x		x	
		Ethylene Liquid																
		Acetylene																
26.	Adiponitrile/HMDA	Butadiene			x		x				x				x			
		Adipic Acid																
		Acrylonitrile																

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
27.	Carbon Tetrachloride	Carbon Disulfide																
		Chloro Paraffins																
		Methane			x						x						x	
28.	Glycerol	Epichlorohydrin																
		Allyl Alcohol									x							
		Acrolein																
29.	Acetone	Cumene			x										x			
		Isopropanol																
30.	Urea	NH_3/CO																x
31.	Toluene Diisocyanate	Diamino Toluene					x				x				x	x	x	
32.	Propylene Glycols	Propylene Oxide																
33.	Acetaldehyde	Ethylene					x											
		Ethanol					x											
34.	Ethyl Chloride	Ethylene			x		x										x	
		Ethanol/Ethane																
35.	Methylene Chloride	Methane			x						x						x	
		Methanol			x						x						x	
36.	Butadiene	Ethylene Coproduct		x	x										x	x		x
		n-butane			x						x				x	x		
		n-butenes			x						x				x	x		

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
37.	Cumene	Benzene Alkylation	X		X						X				X			
38.	Chlorobenzenes	Benzene Chlorination		X			X											
39.	Chloroform	Methane			X						X						X	
		Methanol																
40.	Caprolactam	Cyclohexanone																
41.	Hydrogen Cyanide	Andrussow Process													X	X		
		Acrylonitrile													X	X		
42.	Fluorocarbons	CCl_4/C_2Cl_6 Fluoro.					X				X				X			
43.	Acrolein	Propylene Oxidation					X											
44.	Ethyl Alcohol	Ethylene			X										X			X
45.	Ethanol Amines	Ethylene Oxide													X			
46.	Vinylidene Chloride	1,1,1 Trichloro Ethane	X															
		1,1,1 Trichloro Ethane																
47.	Alkyl Leads	Ethyl Chloride			X										X			
		Electrolysis																
48.	Isopropanol	$Propylene/H_2SO_4$			X			X							X			X
49.	Methyl Isobutyl Ketone	Mesityl Alcohol	X		X		X								X			X
50.	Perchloroethylene	Ethylene Dichloride			X						X						X	
		Methane																

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
51.	Sec-butanol	Butylenes			X						X				X			
52.	Phthalic Anhydride	o-xylene																
		Napthalene																
53.	Pentaerythritol	HCHO/Acetaldehyde			X													X
54.	Bisphenol A	Phenol/Acetone	X								X							X
55.	n-Butyraldehyde	Oxo Process			X						X				X			
56.	Cyclohexane	Benzene			X						X				X	X		
		Petroleum Distillation																
57.	Epichlorohydrin	Allyl Chloride							X		X							
58.	di/Triethylene Glycols	Ethylene Glycol									X							
59.	Dinitro Toluene	Toluene Dinitration	X						X		X					X		
60.	Nonyl Phenol	Phenol Alkylation																
61.	Fumaric Acid	Maleic Acid Isomer															X	X
62.	2-Ethyl Hexanol	Aldo Condensation			X										X			
63.	Ethyl Acrylate	Esterification			X										X	X		
		Acetylene																
64.	Trichloroethylene	Ethylene	X		X						X						X	
		Acetylene																
65.	Methyl Chloride	Methanol			X						X						X	
		Methane																

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption -		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
66.	Diisooctyl Phthalate	Phthalic Anhydride															X	
67.	Ethylene Dibromide	Ethylene Bromination																
68.	Acetylene	H.C. Oxidation			X		X				X				X			
		Calcium Carbide																
		Ethylene																
69.	n-Butanol	Oxo Process			X				X						X			
		Acetaldehyde																
70.	t-Butanol	Propylene Oxide																
		Isobutylenes																
71.	Glycol Ethers	Ethylene Oxide									X							
		Propylene Oxide									X							
72.	Isoprene	Isoamylene Extraction				X									X	X		
		C_4 Hydrocarbons				X									X	X		
73.	Isopthalic Acid	m-Xylene Oxidation																
74.	Ethyl Acetate	Acetic Acid															X	
75.	Propionic Acid	Oxo Process			X						X				X			
		LPG Oxidation																
76.	Acetone Cyanohydrin	Acetone/HCN									X				X			
77.	Benzoic Acid	Toluene Oxidation																

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
78.	Methyl Ethyl Ketone	Sec-butanol				X					X				X		X	X
		Butane Oxidation																
79.	Adipic Acid	Cyclohexane	X	X					X		X					X		X
		Phenol																
80.	Benzene	Toluene Hydrode Alkylation	X		X				X						X			
		Not in Project Scope																
81.	Acrylamide	Acrylonitrile																
82.	α-Methyl Styrene	Cumens Product			X										X		X	
		Others																
83.	Ethylene Diamine	EDC Ammonolysis	X								X							
84.	Methylene Diisocyanate	Diamide/Phosgene							X	X	X							
85.	Phosgene	CO/Cl_2									X				X	X		
86.	Methyl Amines	Methanol Ammonolysis	X		X			X			X							
87.	Isobutanol	Oxo Process			X						X				X			
88.	Diisodecyl Phthalate	P.A./Isodecanol															X	
89.	Isobutyraldehyde	Oxo Process			X						X				X			
90.	Benzyl Chloride	Toluene Chlorination																
91.	Chloronitro Benzenes	Chlorobenzene			X		X				X							
92.	Diethyl (Ethyl) Ether	Ethanol													X			X

TABLE IV
(Continued)

EMISSION CONTROL MODULES

Selection Ranking No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
93.	Linear Alkyl Benzene	Benzene Alkylation					X											
94.	Ethyl Amines	Ethanol Ammonolysis																
95.	Carbon Disulfide	Methane/Sulfur							X		X							
96.	Chloro Acetic Acid	Acetic Acid																
97.	Linear Alkyl Sulfonates	LAB Sulfonation					X											X
98.	Formic Acid	Butane Oxidation			X													
		Others																
99.	Methyl Bromide	Methanol/HBr																
100.	Biphenyl	Toluene/Benzene	X		X				X						X			
101.	n-Butyl Acetate	Butanol/HOAC									X				X			

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TABLE IV
(Continued)

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Rank No.	Chemical	Process	Control Modules															
			Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
102	Benzo phenone	Benzene/carbon tetrachloride																
103	Benzyl benzoate	Benzaldehyde																
		Benzyl alcohol																
104	Aminoethylethanolamine	Ethylene oxide		X													X	
105	Chlorosulfuric acid	(Chlorobenzene)																
106	Dimethyl hydrazine																	
107	n-dimethyl aniline	Aniline/methanol																
108	Hexachlorobenzene	Hexachloro cyclohexane		X			X											
109	Methyl acetate	Acetic acid																
110	n-propyl alcohol	Propionaldehyde													X			
111	Salicylic acid	Sodium phenate																X
112	Diphenylamine	Aniline																
113	Acetophenone	Cumene			X										X			
		Ethylbenzene																
114	Acetychloride	Sodium acetate																
115	Propylene	Naptha/gas oil		X	X										X	X		X
		Natural gas/liquid		X	X										X	X		X
		Refinery byproduct																

TABLE IV
(Continued)

Rank No.	Chemical	Process	Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
116	Aniline	Nitrobenzene hydrogenation					X											
117	Furfural	Polysaccahrides hydrolysis																
118	Butylamines	Butyraldehyde	X		X			X			X							
119	Allyl alcohol	Allyl chloride hydrolysis			X		X				X				X			
		Propylene glycol																
		Propylene oxide													X			
120	Pyridine/picoline	HCHO/acetaldehyde			X										X			
121	Cyclohexylamine	Aniline			X						X							
		Cyclohexanone			X						X							
122	Cresylic acids	Phenol/methanol														X	X	
		Toluene sulfonation														X		
		Cumene oxidation														X		
		Natural coal tar														X		
123	Crotonaldehyde	Aldo process																
124	Hydroquinone	Acetone coproduct			X										X			
125	Isodecanol	Oxo process													X			
		n-paraffin oxidation													X			
126	Isooctyl alcohol	Oxo process			X													

TABLE IV
(Continued)

Rank No.	Chemical	Process	Control Modules															
			Vent Restriction	Droplet Separation	Surface Condensation	Quench Condensation	Contact Condensation	Compression Condensation	Solvent Absorption	Solvent Absorption/Stripping	Chemical Absorption	Carbon Adsorption		Molecular Sieve	Combustion	Vapor Thermal Oxidizer	Liquid Thermal Oxidizer	Particulate Removal
127	Cellulose acetate	Cellulose esterification					X											
128	Isopropyl acetate	Isopropanol																
129	Cyclooctadiene	Butadiene																
130	Dinitrophenol	Dinitrochlorobenzene																
131	Dichlorophenol	Phenol chlorination							X									
132	Butyl acrylate	Acrylic acid																
133	Propylamines	n-propanol	X		X			X			X							
		n-propylchloride	X		X			X			X							
134	Dodecene	Nonene coproduct													X			
135	Nitroaniline	Nitrochlorobenzene																
136	Nitrophenol	Phenol nitration																
137	Ethylene glycol MEE acetate	Ethoxy ethanol																
138	Butyric acid	Butyraldehyde																
		Butane oxidation																
139	Toluene sulfonic acid	Toluene		X							X							
140	Benzoyl chloride	Benzoid acid																

APPENDIX C

ESTIMATES OF TOTAL SOCMI VOC EMISSIONS FOR 1982

ESTIMATES OF TOTAL SOCMI VOC EMISSIONS FOR 1982

A. INITIAL EMISSIONS ESTIMATE

Basis: Survey and Ranking Studies

SOCMI production = 200,000 MM lb (1976)
6% growth = 283,700 MM lb (1982)

140 products address 205,438 MM lb of production (1982) 72.6%
1,584 MM lb of emissions (1982)

283,700—205,438 = 78,262 MM lb of production not covered by survey and ranking studies.

An estimated emission factor for the unranked chemicals was obtained by using the weighted average for the last 25 chemicals ranked on Fig. II-1 (0.0025 lb of VOC emissions/lb of production):

78,262 X 0.0025 = 195 MM lb of VOC emissions from unranked chemicals

1,584 + 195 = 1779 MM lb of VOC emissions for SOCMI in 1982, based on the initial survey and ranking studies.

B. REVISED EMISSIONS ESTIMATE

From Table II-1 the estimated emissions for the products studied are reduced from 1374 MM lb to 733 MM lb, a reduction of 47%. From all indications it appears to be a logical assumption that process emissions would be reduced by a similar amount for the remainder of the industry. However, as discussed in the Fugitive Emissions report of Volume III, fugitive emissions are more a function of equipment count than of production volume. This indicates that the initial VOC emission estimate shown above underestimated fugitive emissions for the large number of plants not studied.

By analysis of Tables II-1 and C-1 it can be seen that the first four products account for more than half of the VOC production addressed by all full-report studies. They are considered to be atypical of the great majority of production sites and were not used to determine emission factors for the remainder of the industry. The VOC emission-to-production-volume ratios for all the remaining full-study reports were used as the basis for projecting the VOC emission

Table C-1. VOC Emission Estimates by Point Source for 1982

	VOC Emissions (MM lb)				
Product	Process	Fugitive	Storage and Handling	Secondary	Total
Acrylonitrile	130.9	1.5	1.5	11.6	145.50
DMT/TPA	93.3	4.0	2.0	Neg	99.38
Ethylene dichloride	87.7	0.5	0.9	1.8	90.92
Ethylene	32.3	33.0	7.3	0.7	73.31
Formaldehyde	19.7	6.9	0.8	Neg	27.42
Cyclohexanol/cyclohexonone	24.7	1.3	0.3	0.3	26.52
Acrylic acid	4.6	7.3	2.5	8.1	22.48
Ethylene oxide	19.9	1.3	0.2	Neg	21.39
Maleic anhydride	9.1	4.4	2.6	0.3	16.46
Ethylbenzene/styrene	7.6	0.9	6.5	0.8	15.75
Ethylene glycol	14.0	0.8	0.1	0.6	15.59
Phenol/acetone	3.1	5.1	1.4	0.1	9.68
Methanol	0.6	3.2	4.4	0.1	8.31
Cyclohexane	Neg	0.9	3.4	0.1	4.40
Chloromethane-methanol	0.8	1.0	2.3	0.1	4.17
Alkylbenzene	1.3	0.6	1.0	0.3	3.17
Chlorobenzene	1.6	0.8	0.2	0.1	2.70
Chloromethane-methane	1.0	0.8	0.5	0.1	2.37
Nitrobenzene	0.4	0.8	0.2	0.2	1.67
Carbon tetrachloride	0.1	0.8	0.3	Neg	1.21
Cumene	Neg	0.4	0.5	0.1	0.98
1,1,1-Trichloroethane	Neg	0.3	0.2	Neg	0.48
Adipic acid	0.1	0.1	Neg	Neg	0.18
Full-study[a]	453 (76.2%)	75.7 (14.0%)	40.1 (6.7%)	25.4 (4.3%)	594
Starting with formaldehyde[b]	108.6 (58.7%)	37.7 (20.4%)	27.4 (14.8%)	11.3 (6.1%)	185

[a] Full-study reports addressed a total annual production of 113,588 MM lb.

[b] All full-study reports (except the first four) starting with formaldehyde address a total annual production of 55,762 MM lb.

estimate for all SOCMI products not covered by a full-study report. Since the ratio of equipment components to production volume increases so dramatically in the many smaller volume plants not studied and since fugitive emissions are more a function of equipment count than of production volume, no fugitive emission factor was developed for processes not covered by study reports.

The emission projection factors derived from Table C-1 are as follows:

$$\text{Process Emissions} \quad \frac{109}{55{,}762} = 0.002 \text{ lb of VOC/lb of production}$$

$$\text{Storage and handling} \quad \frac{27.4}{55{,}762} = 0.0005 \text{ lb of VOC/lb of production}$$

$$\text{Secondary} \quad \frac{11.3}{55{,}762} = 0.0002 \text{ lb of VOC/lb of production}$$

The abbreviated product studies represent 22,425 MM lb of production projected to 1982. Based on the above factors to project the 1982 emission estimates for the abbreviated studies and the 147,627 MM lb of production not covered by full-study reports, the total estimated VOC emissions for 1982 are as follows:

	Amount (MM lb)				
	Process	Fugitive	Storage and Handling	Secondary	Total
Full report studies	453	76	40	25	594
Abbreviated-report studies	45	29	11	4	89
Not studied	294	355	73	29	751
	792	460	124	58	1434
	(55%)	(32%)	(9%)	(4%)	